ELEPHANT-HABITAT INTERACTION AND ITS MANAGEMENT IMPLICATIONS IN RAJAJI NATIONAL PARK

SUMMARY

THESIS

SUBMITTED FOR THE AWARD OF THE DEGREE OF

Doctor of Philosophy

IN

WILDLIFE SCIENCE

BY

AFIFULLAH KHAN

DEPARTMENT OF WILDLIFE SCIENCES
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Introduction

The Asian elephants in India are distributed in four distinct geographical areas in five isolated populations. There are two populations in southern India, one each on either side of the Palghat gap. The other three populations inhabit the central, northeastern and northwestern regions of the country. The northwestern elephant population is smallest comprising of about 1000 individuals. However, a larger part of the northwestern elephant population inhabit Rajaji and Corbett National Parks including the forested areas in between the two. Once contiguous, this stretch of elephant habitat off late has been facing peripheral pressures and fragmentation due to intense human dependence on forest resources and developmental activities. As a result of this, the elephant population in this stretch has been divided into three sub units with little or no movements between them. In such conditions, it was presumed that the confinement of elephant population in smaller areas would be detrimental to their long-term survival and wellbeing. Considering this, the present study was initiated in order to understand elephant-habitat interaction and its management implications in Rajaji National Park, which supports more than one third of the total elephant population in northwestern India. The study had specific objectives to understand the elephant habitat composition and structure, movements and habitat utilization patterns, dietary spectrum and impact of elephant feeding on vegetation and to work out social organization of elephants in Rajaji National Park

Methodology

In order to achieve the objectives of the study several sets of methods were used to collect field data. In addition to the field data I have reviewed the status of the Asian elephant populations in the range countries, which was mainly based on the available literature.

The data on vegetation composition and structure was collected using Point Centred Quarter Method along the stratified transects laid in proportion of availability of different vegetation types. Tree and shrub diversity, richness and evenness values were calculated using Shannon-Wiener diversity, Margalef's species richness indices and Shannon-Weiner function respectively. Sorenson's similarity index (SI) was used to calculate similarity among different habitat types.

To compare the structure and dominance of various species among different vegetation types, Importance Value Index was computed for tree species in different vegetation types. The relationship between tree densities and other habitat parameters was quantified by performing correlation using the Spearman Rank Correlation Coefficient. Tree and shrub density values were statistically compared to understand the differences between different strata, terrain and administrative blocks using one way ANOVA. All statistical tests were performed using computer programme SPSS for Windows (version 10.0).

The data on ranging and habitat utilization pattern of elephants in Rajaji were collected by fixing four radio-collars on different individuals. Locations of each radio-collared elephant were obtained by homing in and were fixed on 1:50,000 scale topographic map of the study area. Home range areas were delineated using Harmonic Mean Transformation method and 90% isopleths were generated. The

95% Bonferroni confidence intervals were constructed to understand the elephant preference to different habitat types.

Data on elephants' dietary spectrum were collected during daytime through direct observations on feeding individuals. The impact of elephant feeding on vegetation was assessed by enumerating damage caused to the trees along 10 m wide belt transects.

The social organization of elephants in Rajaji was studied by recording data through direct sightings of individuals in a group. Whenever, a solitary elephant or a group was encountered its composition and size was recorded. Chi-square goodness of fit test was used to see the differences in the distribution of frequency of sightings between different types of elephant groups. The Kruskal-Wallis one way ANOVA was used to test the differences in the median group size among different seasons.

Results

Population status of the Asian elephants

The total population of Asian elephants in the wild is between 33,600 and 47,835.

There are considerable discrepancies as far as number of elephants in the wild are concerned, mainly due to the lack of proper surveys and inadequate information from several range countries. Most of the information on population size before 1980's, barring a few, is based on educated guesses and hence does not allow to draw any meaningful conclusion on the population trend. However, an analysis of available accounts on the population size of last three decades reveals that in most of the range countries of continental south-east Asia, elephant populations have reduced mainly due to the loss of habitat and fragmentation. Elephant populations in the Indian sub-continent seems to be increasing however in my opinion this may not be a virtual increase in population but more so due to their compression within the protected areas and systematic and consistent efforts in estimating numbers. Population of elephants in Andaman Islands has certainly increased, while no conclusion on the population trend of island Asia (Sri Lanka, Sumatra and Borneo) can be drawn as the existing information is either insufficient or highly discrepant. This certainly calls for consideration of a policy to initiate planned studies to find out the current population status, trends and also monitor population size in various range countries. Concerted efforts for such study are urgently required.

Habitat structure and composition

The vegetation of Rajaji is homogeneous in nature and species are not distinctly arranged in space to form definite vegetation classes. Sal (*Shorea robusta*) is the dominant species occurring all over the area in differential densities. The topographical variation seems to be influencing the density, growth and spatial distribution of various species. A total 71 tree and 46 shrub species were recorded during the study, however, the numbers could be more as rare or less frequent species are likely to be missed in such a large area during sampling. Sal forests were less diverse as compared to mixed forest. The management interventions by the Forest Department had a positive effect on the vegetation, especially the gap filling exercises by raising plantations within the natural forests, have increased the density and diversity of the forest stands. The standing crop is better stocked on the flat and undulating terrain as compared to the slopes and the valleys. Forest blocks such as Gholna, Bam, Betban, and Chillawala had high lopping pressure, which may create an adverse impact on the forests in the form of low regeneration and retardation of tree growth. If the similar trend continued, it would lead to further degradation of the forest stand. Low regeneration of *Shorea robusta, Anogeissus latifolia, Terminalia alata, Dalbergia sissoo* and *Pinus roxburghii* may cause gradual replacement of these species by those species showing high regeneration such as *Acacia catechu, Ougeinia oogeinsis, Mallotus philippensis,* and *Ehretia laevis.* High densities of *Lantana camara* and *Adhatoda zeylanica*, at several places especially in forest blocks such as Baniawala, Lalwala and Tira had out competed other species contributing low richness and diversity at shrub level.

Ranging and habitat utilization patterns

The ranging pattern of elephants in the Rajaji indicated that there were marked variations in the home range sizes of male and female groups. The home ranges of males were larger than that of the females and the reasons attributed to this include; restricted movements of female groups due to the presence of juveniles, maintenance of cohesiveness among the members of the group, male's strategy to explore new areas and finding mates. The seasonal variation in range sizes and habitat use patterns were largely due to the differential availability of good quality forage among different habitat types when water was available at a convenient distance from the foraging sites. During summer, when most water bodies dried up, the elephants were observed compromising the quality of habitat they occupy over the availability of water. Female choice of mate may influence range size among males.

Apart from the above it was also conclusively established that the genetic continuity among the two sub groups of elephants inhabiting Rajaji-Motichur and Chilla units is maintained by occasional movements of solitary males and hence protection of corridor between the two units is of utmost important. However, the movement of female groups through the corridor was not evident. It is discernible from the movement pattern of elephants that the year round utilization of the resources of Rajaji WLS by the present population may not be sustainable and therefore part of the elephant population moves during summer to areas not frequented by elephants at least in the recent past.

Feeding ecology and its impact on vegetation

The bulk of elephant diet in Rajaji was composed of browse material. Grasses constitute only about 5% of elephant diet. Such low proportion of grasses in the diet was due to the low availability of grasses in the Rajaji as compared to other elephant areas. There were seasonal fluctuations in the consumption of grasses. Grasses were eaten in higher proportions during monsoon and least during summer. The reasons for seasonal variations in grass consumption were palatability and nutritive values, which differ seasonally. Elephant browse component of diet was comprised of 38 species, of which 33 were recorded eaten through direct observations while rest five species were recorded through evidences. However, the bulk of elephant diet was composed of 10 browse species accounting for more than 70% of the diet. Only four browse species were recorded eaten by elephants in higher proportions while 17 species were eaten in equal proportions and 6 species were consumed in lower proportions to their availability in Rajaji. *Mallotus philippensis, Aegle marmelos, Bauhinia malabarica* and *Stereospermum suaveolens* were the preferred food species of elephants. Among the different plant parts, bark consumption was highest followed by branches and leaves. However, there were seasonal fluctuations in the proportions of different plant parts in the diet of elephants. Pushing over was the most frequent type of damage to the trees caused by elephant feeding and was the reason for tree mortality. Stem twisting was recorded in low percentage, a few trees were also found dead due to this. Other type of damage such as crown breaking and debarking did not cause tree mortality and had minimal impact on trees. The overall mortality caused by pushing over and stem twisting was 5% but the mortality in certain species such as *Mallotus philippensis, Bauhinia malabarica* and *Garuga pinnata* was recorded between 6% and 8%. The populations of tree species such as *Aegle marmelos, Garuga pinnata* and *Dalbergia sissoo* were adversely affected due to mortality inflicted by elephant feeding and poor regeneration. If the damage to these trees continued with the present rate than it is expected that the populations of these tree species would eventually be replaced by other species or would simply be reduced to an alarming level in near future.

Social Organisation

Asian elephant in the Rajaji National Park forms small groups. The majority of groups are comprised of up to 15 individuals and the mean group size of female groups ranges between 7.66 and 8.37. The mean group size seems to be influenced only by the availability of water as during summer comparatively larger groups were observed. Other parameters, such as season, vegetation type and terrain types, do not influence the group size. The adult males usually remain solitary but some time form small groups up to 7 individuals, however, the association between the individuals is just by chance encounters. Majority of female groups accompany male(s) but the males do not show any fidelity towards a particular female group. The stable relationship is between a female and her one offspring usually either a small or a large calf and can be regarded as family unit. All other associations either between individuals of cow-calf groups, male-female groups or mixed groups are due to chance encounters and do not show any definite pattern that can explain certain relationship.

Status of Rajaji-Corbett Corridor (KEC)

The belt of reserved forest between Rawasan and Saneh rivers form the corridor between Chilla and Kalagarh Forest Division, which is contiguous with Corbett NP.

Of importance, within the corridor is the area between Malan and Khoh rivers (section II). The forest within corridor area is degraded as evident by low densities of tree species. There are pockets within the corridor especially in section II where the biotic pressures are concentrating and as a consequence of it elephant movement and utilization in such areas is adversely affected. Given proper protection and management of biotic pressures, the habitat can recover from its present state, which in turn would facilitate frequent elephant movements through the corridor.

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(Afifullah Khan)

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Chapter 1: Introduction

1.1 Rationale

Super imposition of man's pattern of landuse and changing life style in response to new world order has created an adverse impact on natural resources all over the world and especially in the developing countries. The worst affected natural resources are the forests and wildlife therein. Large-scale clearance of natural habitats, reckless exploitation of plant and animal resources, encroachment on wilderness areas for development of townships and industries, all of them have led to degradation, shrinkage and fragmentation of once vast immaculate natural areas into small islands surrounded by Human Ocean. As a result of this, several wildlife species have become extinct and many others are facing serious threats for their existence and survival. In India alone, as many as 77 mammalian species have been classified as highly endangered and they are listed in the schedule I of "The Wildlife (Protection) Act 1972". The Asian elephant (*Elephas maximus*) is one of them.

The Asian elephant in India, once ranged over almost whole of the geographical area of the country barring high hills of the Himalayas and the Indian deserts, now survive only in five isolated populations in four distinct geographical provinces. Among them, the northwest Indian population of elephants is smallest, comprising of about 1000 individuals, distributed over an area between river Yamuna and to some distance across the river Sharda up to Dudhwa National Park. However, about 90% of northwest Indian population of elephants inhabit Rajaji and Corbett national parks including the reserved forest area in between the two. It is this stretch of elephant habitat, which has been fragmented and developed bottlenecks at two places dividing the population in to three sub units. These three sub unit are; the western Rajaji unit comprising of Rajaji and Motichur wildlife sanctuaries (WLS), the Kotdwar unit comprising of Chilla WLS and part of Lansdown Forest Division and the Corbett unit comprising of Sonanadi WLS and the Corbett National Park (Fig. 1.1). It was believed that the degradation and loss of habitat and heavy human interference at the bottleneck areas had off late hampered the seasonal movement of elephants between these three units. It was envisaged that the confinement of sizable elephant population within the small isthmus would lead to over utilisation of resources which in tern would leave northwest elephant population vulnerable to environmental as well as genetic stochasticity. It was this concern that formed the basis of this study with the following objectives, in order to draw a management and conservation policy for the long-term survival of the elephant population in this region.

1.2 Objectives

1. To describe and evaluate the vegetation structure and composition of elephant habitat in Rajaji National Park.
2. To study the ranging and habitat utilisation pattern of elephants in Rajaji National Park.
3. To investigate the dietary spectrum of elephants in Rajaji and to evaluate the impact of feeding on the vegetation.
4. To understand the social organisation of elephants.

1.3 Organisation of thesis

There are eight chapters in this thesis. Each chapter (chapters 4 to 8) has five sections; the introduction, methodology, results, discussion and summary and conclusions. All tables, graphs and figures are appended at the end of each chapter. All references sighted in the text are appended at the end of this thesis. Following is the details of each chapter.

Chapter 1 introduces the subject of this study, objectives and organisation of the thesis and reviews brief historical account of research, so far carried out on the ecology of the Asian elephant.

Chapter 2 introduces the Rajaji National Park in terms of its location, geology and soil, climate, fauna and flora.

Chapter 3 provides information on the current status and distribution of the Asian elephants in the range countries and is mainly based on the available information.

Chapter 4 deals with habitat structure and composition. It provides detailed description of density, diversity, evenness of tree and shrub species in different vegetation types. It also deals with tree population structure, status of lopping and its impact on the population structure.

Chapter 5 describes the ranging and habitat utilisation pattern of elephants in the Rajaji National Park.

Chapter 6 deals with the food and feeding of elephants in Rajaji. It provides details about the seasonal variations in dietary spectrum and possible factors influencing it. It also deals with the types and extent of damage to vegetation due to elephant feeding and its impact on to various food plant species.

Chapter 7 provides information on social organisation of elephants in the study area.

Chapter 8 addresses the conservation issues of the elephant population in the northwest India and deals with the management implications of the present study.

1.4 A historical perspective of elephant research in Asia

Elephant has been a part of the culture of most Asian countries especially India since the time immemorial. The documentation of elephant's life, habit and its management in captivity began as early as 20th century B.C. The ancient Hindu mythological literature such as the Rig Veda of about 20-15 century BC, Upanishad and the Gajaha-shastra of 9–6 century BC illustrates this. Moghul writings of medieval period such as Ain-e-Akbari and Tuzuk-e-Jahangiri find mention about the distribution and aspects of natural history of elephants. Ali (1927) highlighted the contribution of Moghul Emperors to the natural history of several animals including elephants.

During 19th century, the British Civil and Forest Service officers, travellers and/ or naturalists documented the aspects of natural history and distribution of elephants (e.g. Jerdon, 1874; Bradley, 1876; Sanderson, 1882). This trend continued into the early 20th century and several naturalists continued to document natural history and distribution of Asian elephants. During later half of the 20th century, Williams (1950), Baze (1955), Gee (1964), Kurt and Nettasinghe (1968) documented their experiences and observations on the status, distribution and several accounts related to elephant's ecology and biology.

During 1970's, Sri Lanka took the lead when Eisenberg *et al.* (1971) published an account on the reproductive behaviour of Asiatic elephants. Eisenberg and Lockhart (1972) carried out an ecological reconnaissance of Willapattu National Park and Jainuddin *et al.* (1972a, 72b) studied the reproductive physiology and behaviour. At the same time, Mueller-Dombois (1972) studied the effect of elephant distribution on woody vegetation of Ruhuna National Park. McKay (1973) however, set the tone of ecological research on Asian elephants. His three-year work, carried out in Gal Oya and Ruhuna National Parks was the first comprehensive scientific documentation in which he touched upon several aspects of elephants' behaviour and ecology. It was followed by the work of Kurt (1974) on the social structure and Vancuylenberg's (1977) on feeding behaviour of the Asian elephants in southeast Sri Lanka. Another detailed ecological study was in progress in Malayan rain forests, which culminated in to a Ph.D. thesis by Olivier (1978). However, some preliminary work on Malayan elephants had already been carried out by that time (Khan bin Momin, 1977 b, c & d).

Ecological research in Sri Lanka continued well in to 1980s. Ishwaran carried the work of Vancuylenberg forward and two key publications appeared out of his study conducted at Gal Oya National Park. The first one was on comparative study of elephants (Ishwaran, 1981) and the second was pertaining to elephant and woody plant interaction (Ishwaran, 1983). Santiapillai *et al.* (1985) carried out yet another study on the ecology of Asian elephants. Katugaha *et al.* (1999) reported the results of a long-term investigation conducted in Ruhuna National Park on the population dynamics. In Sumatra, Nash and Nash (1985) carried out a detailed study in Padang Sugihan Wildlife Reserve on the status and ecology of Sumatran elephants.

Elephant research in India was in its infancy even during 1970's. Creation of the Asia Elephant Specialist Group (AESG) in 1976 has generated interest among the field biologists. The group emphasised the need to carry out surveys in order to understand the precise status and distribution of elephants in its present geographical range within India. Working on the mandate of the AESG, Daniel (1980) prepared first comprehensive report on the status and distribution within four geographical regions holding elephant populations. Prior to the report of Daniel, some information on the status of elephants from localised areas was available (e.g. Singh, 1969 & 1972; Singh, 1978; Nair & Gadgil, 1980) and also an exclusive study by Lahiri-Choudhury (1975) on the depredation problem in a forest division of West Bengal.

The status surveys and population estimation continued well in to the next decades. Lahiri-Choudhury (1985), Choudhury (1991 & 1995) and Williams and Johnsingh (1996) documented the status and distribution of elephants in parts of northeast India. Singh, (1986) and Singh (1995) estimated size of northwest elephant population while Anon (1993), Appaya (1995), Easa and Balakrishnan (1995) documented status and distribution of elephant populations in south India. Datye and Bhagwat (1995a) reported the status in Bihar and Singh (1995) documented the same in Orissa.

Ecological research on elephants in India started a little later as compared to Sri Lanka and also Malaysia. The Bombay Natural History Society launched an endangered species project, which covered aspects of ecology of elephants and their habitats (e.g. Ali *et al.*, 1984; Ali *et al.*, 1985). Sukumar (1985) carried out first long-term comprehensive study covering aspects of feeding ecology, social organisation, movement and habitat utilisation and man-elephant interaction in south India. The Wildlife Institute of India in 1984 initiated a study on the movement and habitat utilisation of elephants in northwestern Uttar Pradesh. Under this project, elephants were immobilised (Sale *et al.*, 1986) and for the first time elephants were radio-collared. Detailed investigations on ranging and habitat utilisation pattern were carried out, but the results of the study largely remained unpublished barring a preliminary project report by Johnsingh *et al.* (1989).

Considerable attention was being paid to the ecological research on elephants during 1980s and thereafter. Several studies were reported on elephant movements, ranging pattern, habitat utilisation and aspects of feeding ecology. Easa (1988) documented movement pattern in Prambiculam Wildlife Sanctuary. Ramachandran (1990) conducted studies on migration of elephants in Wayanad Wildlife Sanctuary. Desai (1991) calculated home range of elephants in Mudumalai Wildlife Sanctuary and discussed its implications for management. Joshua and Johnsingh (1995) worked out home range of a bull and a female in Rajaji National Park and based on the ranging pattern suggested realignment and extension of park's boundary. Bhaskaran *et al.* (1995) using radio-telemetry, carried out a study on the ranging pattern of an elephant clan in Nilgiri Biosphere Reserve, South India. Datye and Bhagwat (1995 b) in an ecological investigation conducted on central Indian population estimated home range of elephants in fragmented habitat. Desai and Bhaskaran (1996) documented the impact of human disturbance on the ranging behaviour of elephants in Nilgiri Biosphere Reserve.

Sukumar gave first detailed treatment to various aspects of feeding ecology of Indian elephant starting from simple qualitative and quantitative assessment of diet to reviewing elephant feeding strategy in relation to optimal foraging (Sukumar, 1985 & 1990; Sukumar *et al.*, 1987; Sukumar & Ramesh, 1992 & 1995). Sivaganesan and Johnsingh (1995) worked out dietary spectrum and assessed the status of crude protein among various species of grasses consumed by elephants in Mudumalai Wildlife Sanctuary. Sivaganesan and Sathyanarayana (1995) based on seven years of monitoring, documented mortality to various tree species caused by elephant feeding in South India. Apart from the detailed study by Sukumar (1985), Sivaganesan (1992) and later by the team of BNHS (Daniel, 1995) on the ecology of elephants, few other short-term investigations on various aspects of elephant ecology were carried. Nair & Jayson (1990) reported interaction between elephant and teak plantation, Tiwari (1990) working in Prambiculam Wildlife Sanctuary carried out a study on the habitat utilisation, Kishan (1990) reported results of a study conducted on the ecology and behaviour of elephants in Andhra Pradesh. Mohana (1990) worked out population dynamics in Periyar Tiger Reserve. Brahmchary (1995) documented the seed dispersal of six plant species by elephants in Chandaka, Orissa. After 1980, apart from documentation of status, distribution and ecological and behavioural studies as reviewed above, the research on Asian elephants entered into the next phase in which emphasis was given to highlight man elephant conflict, conservation and management issues and more recently, population dynamics and physiology. The pioneering work of Sukumar in 1985 on man elephant interaction and afterwards (Sukumar & Gadgil, 1988; Sukumar, 1990) on the crop raiding pattern and behaviour probably gave a direction to other workers in India and several studies pertaining to aspects of man-elephant conflict were carried out. Menon (1990) highlighted the problem of crop raiding in Andhra Pradesh while Nair (1990) in Kerala, Balasubramanian *et al.* (1995) in Nilgiri Biosphere Reserve, Datye and Bhagwat (1995c) in Dalama Wildlife Sanctuary, Dey (1991) in north Bengal forests, Veeramani and Jayson (1995) in Kerala, carried out studies on various aspects of crop depredation by elephants. Other studies on man elephant conflict issues include Ramakrishnan and Sukumar (1991), Menon (1989), Datye and Bhagwat (1995d), Talukdar (1996) and Ramakrishnan *et al.* (1997). An exclusive detailed study on elephant human conflict carried out under the aegis of the Asian Elephant Research and Conservation Centre, Bangalore has produced a series of reports (e.g. Sar & Lahiri-Choudhury, 1999 a & b; 2000; 2001; 2002 a, b

& c; Gurung & Lahiri-Choudhury, 2000 & 2001). Elsewhere, Nyhus *et al.* (2000) documented the problem of crop depredation by elephants and its conservation implications at Way Kambas National Park, Sumatra. Tisdell and Zhu (1998) studied the economic losses incurred due to the crop depredation by elephants in protected areas in Yunnan province. Zhang and Wang (2003) focussed on the problem of elephant–human conflict vis-à-vis conservation of habitat in Simao, China.

An enhanced knowledge about elephant populations, conservation needs, man–elephant conflict and increasing human pressure on the existing elephant habitats prompted conservationists to focus on the elephant management and conservation issues. Santiapillai and Suprahman (1984) suggested habitat management in Way Kambas Game Reserve. In a series of articles between 1982 and 1995, Jayawerdene documented the challenges faced by the elephant populations in Sri Lanka due to the upcoming development projects and suggested conservation measures (Jayewardene, 1984; 1986 a & b; 1989; 1994; 1995 a & b). Rudran *et al.* (1995) stressed on the need to adopt an integrated approach for elephant conservation in Sri Lanka. Fernando (1995) advocated for using Minimum Area Requirement concept in relation to the elephant conservation in Sri Lanka.

In India too, Johnsingh (1989) reviewed the conservation status of elephants within protected areas. Again, Johnsingh and Panwar (1989) brought in prominence the conservation problems of elephants. Johnsingh and Williams (1999) stressed the need of habitat continuity and highlighted the importance of corridors in long-term conservation of elephant populations. Sukumar (1995) working on population dynamics suggested minimum viable population size for short-term conservation of small and isolated populations. Several area specific studies were also carried out in

India highlighting conservation and management issues. Uniyal and Easa (1990) suggested management options for the elephant population of Prambiculam Wildlife Sanctuary. Barua (1995) documented the elephant problem in areas between Teesta and Torsa rivers in North Bengal and suggested translocation as the management option. Neelkantan (1995) summarised the elephant conservation problems in Tamil Nadu and suggested involvement of local communities in sustainable development to ensure protection to elephant habitat. Tyagi (1995) presented the conservation scenario in Mudumalai Wildlife Sanctuary and suggested several measures for effective management of elephant habitat and population. Khan (1995) working on the north- west population of elephants stressed the need for creation of an elephant conservation unit between Rajaji and Corbett national parks to prevent further fragmentation of elephant population in the region.

Elsewhere, Htut (1995) documented the management practices in Myanmar, Daim (1995) suggested translocation as a technique to manage problem elephants in Malyasia. Xiang & Santiapillai (1995) summarised the conservation problems of elephants in China and stressed the need to resolve human elephant conflict in order to ensure long-term conservation. Santiapillai (2001) documented the effect of deforestation and its implications in conserving elephant populations in Sri Lanka and Sumatra.

During the 1990's, efforts were also made to take a holistic view of elephant conservation at regional, national and global level. Santiapillai and Jackson (1990) developed an action plan for the conservation of Asian elephants. Also, Santiapillai and de Silva (1994) proposed an action plan for the conservation and management of elephants in Sri Lanka. Johnsingh (1994) prepared an action plan for the conservation of northwest Indian population. Santiapillai (1997) designed a global strategy for the conservation of Asian elephants.

The need of developing scientific methodology was felt to estimate population size and densities of elephants and several studies were undertaken to accomplish this task. Initial trials on developing an indirect method of counting elephants in forests were conducted by me with the technical inputs from A.J.T. Johnsingh and J.B. Sale in Rajaji National Park and later the concept was discussed at a workshop conducted by the AESG in Mudumalai Wildlife Sanctuary (Sale & Johnsingh, 1988). Sale *et al.* (1990) reported the results of preliminary trials on estimating elephant numbers through counting dung piles. After more field trials and refinements in the overall methodology, Dekker *et al.* (1991) developed a manual on counting Asian elephants in forest through an indirect method. Hiby and Lovell (1991) developed a computer programme 'DUNGSURV" for estimating elephant densities form the dung density data while Karanth (1991) demonstrated the use of line transect method in censusing elephants in Nagarhole National Park. The AESG workshop conducted on censusing elephants in forests recommended that direct and indirect (dung) count using line transect method as developed by Burnham *et al.* (1980) should be used instead of total count. Verman *et al.* (1995) working in Mudumalai Wildlife Sanctuary compared the results of direct and indirect methods in estimating elephant densities and concluded that in order to achieve precision in estimating elephant densities closer to the population mean, more work is needed. However, Santosh and Sukumar (1995) suggested ways to overcome the problem in estimating elephant densities.

1.5 Status of research conducted on study population

Prior to my own study, which was initiated in 1986, the only information on northwest elephant population was on the status and distribution. Three status surveys were conducted by Singh (1969, 78 & 86) covering nine forest divisions having elephant populations. The results of these surveys highlighted the problem of habitat fragmentation and division of elephant population into smaller sub population due to the impediment of seasonal movements through traditional routes due to the increased human interference and development activities. Considering this, the Wildlife Institute of India initiated a research project on the seasonal movement and habitat utilisation patterns of elephants in northwestern Uttar Pradesh. I joined this project in September 1986 and carried out fieldwork till July 1989. Johnsingh *et al.* (1989) prepared a summary report. Several short-term investigations have also been carried out. Johnsingh *et al.* (1990) assessed the conservation status of Chilla-Motichur elephant corridor and stressed the need for conservation of Rajaji-Corbett ecological complex for long-term survival of elephants. Joshua and Johnsingh (1995) described the ranging pattern of elephants in Rajaji National Park and recommended extension of the Park's boundary. Johnsingh (1994) put forth an action plan for the conservation of elephants in north-west India. Sunderraj *et al.* (1995) and Khan (1995) assessed the status of Rajaji-Corbett corridor and suggested management options for long-term conservation of elephants in north-west India.

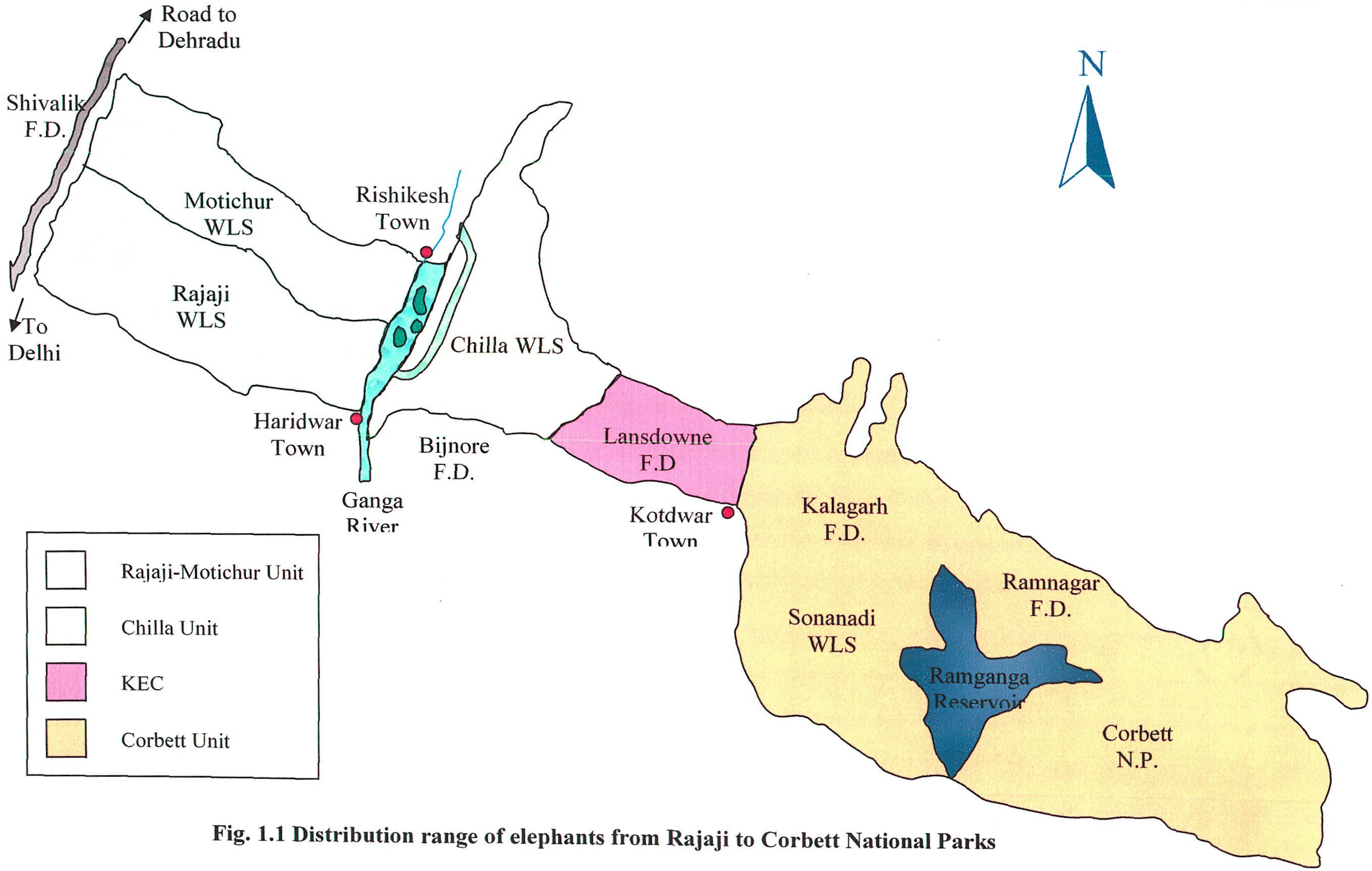


Fig. 1.1 Distribution range of elephants from Rajaji to Corbett National Parks

2.1 Location of the Rajaji National Park

The Rajaji National Park is located at 77° 57' 7" to 78° 23' 36" East and 29° 51' 7" N to 30° 15' 50" North in the districts of Haridwar, Dehradun and Pauri Garhwal of Uttranchal State of northern India. The National Park is bounded in the west by Delhi-Dehradun highway and is contiguous with Lansdowne Forest Division in the east. To the south, it extends up to the areas of intensive cultivation that opens up in the Gangetic plains while to the north the park extends up to the base of Shivalik hills, which meets the Doon valley. The River Ganges divides the Rajaji National Park into two portions as it flows through the park for about 20 km. The eastern portion of the park is comprised of the former Rajaji and Motichur Wildlife Sanctuaries while the western portion includes former Chilla Wildlife Sanctuary (Fig. 2.1). This study was carried out in the former Rajaji and Chilla Wildlife Sanctuaries, however the intensive study area was former Rajaji Wildlife Sanctuary thereafter referred as Rajaji.

2.2 Brief history of the Rajaji National Park

The history of conservation status of Shivalik Forests in which the Rajaji National Park is located, prior to the 19^{th} Century is more or less shrouded and not much authentic information is available. A large forest tract of Shivalik was declared as Reserved Forest towards the end of 19^{th} Century and was divided into several administrative units, with definite boundaries after repeated demarcations and delimitation. The position, however, stabilised during the early 20th Century and the region of Shivalik between the Yamuna and Ganga was divided into three forest divisions viz.; the Shivalik Forest Division, Dehradun East and Dehradun West forest divisions. The forest east of the Ganga was under the Lansdowne Forest Division.

In 1966, an area of 90 km^2 of Dehradun East Forest Division was upgraded as Motichur Wildlife Sanctuary. Later, in 1967 an area of 249 km^2 of Shivalik Forest Division and in 1974 an equal area of Lansdowne Forest Division was declared as Rajaji and Chilla Wildlife Sanctuaries respectively. In 1984 these three sanctuaries and part of Shivalik, Dehradun and Lansdowne forest divisions comprising an area of about 820 km^2 was integrated and declared as Rajaji National Park.

2.3 Geology and Soil

The paleontology of the Shivalik system, according to Wadia (1975) extends from the middle Miocene to the lower and middle Pleistocene. The Shivalik topographically belongs to the mountains but geologically to the plains and are composed of the same material that forms the deposits of the level plains of northern India and hence classified as Upper Gangetic Plains by Rodgers and Panwar (1987). The Shivalik range, formerly the northern most belt of the flat alluvial region was separated from the outer Himalayas by counter reverse faults or lateral compressions into long fold or range and is composed of riverain debris of Himalayan origin.

Geologically the Shivalik range form the outer part of the sub-Himalayan zone and is composed of the rocks of tertiary age. Based on the characteristics of the composing rocks the Shivalik hills are divided by the geologists into three classes; the upper Shivalik conglomerate stage, middle Shivalik sandrock stage and lower Shivalik sandstone stage. These three stages of Shivalik are predominant types but do not constitute distinct formations as the conglomerate is found also in the sandrock stage, especially towards the base of Shivalik, as well as in sandstone stage while clay and loam are found throughout the whole series. In Rajaji National Park, all three stages of Shivalik are found. The soil of the hills and submontane areas are mostly poor dry and shallow sandy loam. In the moist and better-stocked areas such as the gentle northern aspects and base of the hills towards the plains, the soil is covered by humus and has become a good loam.

2.4 Topography

The topography of the Rajaji National Park largely consists of the Shivalik hills. In western part of the park, the spine of the Shivalik lies mainly on the northwest to the southeast axis. The highest peaks along the spine are around 1200 m in height with gentle northern slopes falling into Doon Valley. The southern slopes are deeply dissected and steep, forming a series of sharp ridges interspersed with V shaped valleys running from east to southwest. The southern slopes level off to flat ground at about 300 m above mean sea level on the southern boundary of the Park. The eastern portion of Rajaji National Park consists of alluvial land rising in a series of steep dissected hills contiguous with outer Himalayas in the north. The altitude reaches to about 1800 m above mean sea level in outer Himalayan Hills.

The Shivalik are subjected to extensive erosion due to its fragile nature, particularly that resulting from rapid run off during heavy rains. Gullies and landslides are common and the valley bottoms and the rivulets are mostly strewn with boulders and pebbles. The steep hills running down from the main Shivalik spine which are interspersed with gorges and deep valleys, widen out as the slopes become gentle thus forming open flat bottomed river beds locally called as 'Rau'.

2.5 The Climate

The characteristic features of the climate in the study area are extreme variations in temperature and humidity in different seasons of the year. There are three distinct seasons namely the winter, summer and monsoon.

The winter normally starts in early November and extends till mid March. This season is characterised by bright days and cold nights. Humidity is comparatively low from December to February but with heavy dew. During December and January, mornings are foggy. Some time fog is so thick that it reduces visibility beyond 20-30 m and persists most of the day. The area receives occasional winter rains (between 50 & 80 mm) during December and January.

The summer starts from mid March and extends up to mid June. March and April are pleasantly warm during daytime and cool during the nights. May and June are the hottest months with maximum temperature often rising up to 40° C. During this season, dust particles remain suspended in the atmosphere. Sand storms of short duration are common during April and May. Occasionally thunderstorms, often accompanied by hail do occur which decreases the temperature temporarily. Rise of temperature during summer often favours forest fires.

Monsoon usually breaks during the middle of June and continues until mid September and sometime until the end of the month. This season is characterised by heavy rains and an almost saturated atmosphere with little variations in temperature. July and August are the months of heavy rains and the area experiences flash floods.

2.6 Temperature and rainfall

There are extreme variation in temperature and rainfall. December and January are the coldest months in which daytime temperature ranges between 12° C and 20° C while the night temperature ranges between 2° C and 6° C. In summer, May and June are the hottest months in which the daytime temperature ranges between 25° C and 38° C. However, sometime the temperature reaches up to 41° C. The night temperature also remains high and ranges between 19° C and 24° C. After the monsoon breaks, the temperature gets slightly milder and ranges between 15° C and 32° C. Mean monthly temperature values are given in Fig. 2.2.

The area receives approximately 2000 mm rainfall annually, however, about 90 percent of rainfall is in between June and September. July and August are the wettest months and the average rainfall in each month is about 600 mm. Figure 2.3 presents the mean monthly rainfall values for the study area.

2.7 The vegetation

The vegetation of Rajaji National Park is mainly composed of heterogeneous deciduous species of tropical and sub-tropical origin, a typical characteristic of central sub Himalayan tract with an average annual rainfall of about 1200 mm (Singh, 1968). The vegetation is affected by the variations in altitude and topography. In Rajaji too the forest on the upper Shivalik is different from submontane areas and flat alluvial plains. According to the forest classification of Champion & Seth (1968), following forest types can be recognised in Rajaji National Park.

(1) Sub-type 3C/C2a. Moist Shivalik sal forest

(2) Sub-type 5B/C1a. Dry Shivalik sal forest

(3) Sub-type 5B/C1b. Dry plain sal forest

(4) Type 5B/C2. Northern dry mixed deciduous forest

(5) Sub-type 5/E9. Dry bamboo brakes

(6) Type 5/1S2. Khair-Sissoo forest

(7) Sub-type 9/C1a. Lower or Shivalik chir pine forest

Since the vegetation of Rajaji is homogenous and the recognition of above forest types requires in depth knowledge of species composition along with soil characteristics and rainfall pattern, therefore a simple classification of broad vegetation types was proposed for the purpose of present study, which can be easily recognised. An in depth treatment to the vegetation composition and structure of Rajaji Sanctuary is given in chapter 4. However, based on the structure, vegetation composition and topographic features five major vegetation types were recognised in Rajaji National Park.

(1) Miscellaneous forest on hills

(2) Miscellaneous forest on plains

(3) Sal forest on hills

(4) Sal forest on plains

(5) Plantations

2.7.1 Miscellaneous forest on hills

Mostly this vegetation type is found on the southern slopes however, sizable patches are also found on northern slopes where topography is rugged. The common tree species are *Anogeissus latifolia, Kydia calycina, Acacia catechu, Bauhinia purpurea, Buchanania lanzan, Ehretia laevis, Gardenia turgida, Garuga pinnata, Holarrhena pubiscens, Ougeinia oogeinsis, Pinus roxburghii, Terminalia tomentosa, Ziziphus xylopyra, Dalbergia sissoo, Grewia elastica, Lannea coromandelica, Litsea chinensis, Miliusa velutina, Mitragyna parviflora, Bombax cieba, Shorea robusta, Sterculia villosa and Cassia fistula.* Other species of minor occurrence include *Edina cordifolia, Aegle marmelos, Albizia odoratissima, A. procera, Bauhinia malabarica, Bridelia retusa, Casearia tomentosa, Cordia myxa, C. vestita, Emblica officinalis, Ficus benghalensis, F. religiosa, F. rumphii, Grewia oppositifolia, Holoptelea* *integrifolia, Limonia acidissima, Nyctanthes arbortristis, Randia dumetorum, Semecarpus anacardium* and others.

The undergrowth is sparse on steep slopes, however on gentler slopes the understory consists of species such as *Mallotus philippensis, Adhatoda zeylanica, Colebrookia oppositifolia, Helicteres isora, Murraya koenigii* and *Woodfordia fruiticosa* etc. Only one species of bamboo *Dendrocalamus strictus* is found in this area, which is mostly confined on the hillsides along the 'Rau'. The quality and growth of bamboo is poor due to intensive cutting in the past, repeated fires, overgrazing by cattle and wild animals especially elephants. Few sizable patches can be seen at the southern boundary of former Rajaji Sanctuary, which are mainly old plantations but now have assumed a character of natural vegetation.

Most of the steep hill slopes are devoid of shrub story and have good grass growth. Small patches of grass along the hill slopes where tree canopy is sparse are of common occurrence. The most common grass species growing on steep slopes is *Eulaliopsis binata.* The other grass species growing are *Desmostachya bipinnata, Chrysopogon fulvus, Heteropogon contortus, Digitaria violascens, Apluda mutica and Setaria gluca* etc.

2.7.2 Miscellaneous forest on plains

This vegetation type is less diverse as compared to the miscellaneous forest on hills but have higher density of trees. The most common species growing as the underwood is *Mallotus philippensis*, which also forms the bulk of elephant diet. The upper canopy tree species of common occurrence are *Dalbergia sissoo, Acacia catechu, Ehretia laevis, Lagerstroemia parviflora, Kydia calycina, Miliusa velutina, Shorea robusta* and *Randia dumetorum.* Other species of frequent occurrence are *Albizia lebbeck, Azadirachta indica, Bauhinia malabarica, Butea monosperma,* *Casearia tomentosa, Cassia fistula, Holarrhena pubescens, Grewia elastica, Flacourtia indica, Litsea chinensis, Stereospermum suaveolens, Terminalia bellirica* and *Ziziphus xylopyra*. Apart from them several species occur in low densities such as *Bauhinia purpurea, B. variegata, Bombax ceiba, Emblica officinalis, Ficus rumphii, Gardenia turgida, Garuga pinnata, Gmelina arborea, Holoptelea integrifolia, Limonia acidissima, Mitragyna parvifolia, Ougeinia oogeinsis* and *Premna latifolia* etc.

The shrub story is dense but with fewer species as compare to miscellaneous forest on hills. The shrub story is mostly dominated by *Lantana camara* along the paths and roadsides and also at places where tree canopy is open. At the forest edges towards the southern boundary of the National Park the growth of *Lantana camara* is so profuse that no other shrub species grow there. At places where tree canopy cover is moderate, *Adhatoda zeylanica* is the dominant shrub. Other species forming shrub story in this vegetation type include *Murraya koenigii, Colebrookea oppositifolia, Xeromphis spinosa, Ziziphus nummularia* and *Cassia tora* etc.

As such no grassland exists on flat terrain of Rajaji National Park. Only small patches are found at the places where tree canopy is open or along the 'Rau' and at the raised Rau beds. The dominant grass species growing in such areas are *Imperata cylindrica, Cynodon dactylon, Eragrostis unioloides, Sporobolus diander, Desmostachya bipinnata, Themeda gigentica* and *Veteveria zizanioides*. The grass species growing along the 'rau' include *Saccharum munja, S. spontaneum, Erianthus ravennae* etc.

2.7.3. Sal forest on hills

Sal (*Shorea robusta*) is usually confined to gentler slopes, along the "Nala' and hollows where soil layer is thick. Tree species of common occurrence growing with sal are *Anogeissus latifolia, Bauhinia purpurea, Buchanania lanzan, Ehretia laevis, Kydia calycina, Ougeinia oogeinsis, Pinus roxburghii, Syzygium cumini and Terminalia tomentosa.* The under canopy is mostly dominated by *Mallotus philippensis.* Other species of minor occurrence growing in this vegetation type include *Albizia procera, Cordia myxa, Gardenia turgida, Garuga pinnata, Grewia elastica, Litsea chinensis, Flacourtia indica, Ficus benghalensis, Dalbergia sissoo, Cassia fistula, Casearia tomentosa, Albizia lebbeck,* and *A. procera* etc. *Helicteres isora, Holarrhena pubescens,* and *Adhatoda zeylanica* are the most common species occurring at shrub level.

2.7.4 Sal Forest on plains

Patches of sal forest are found on almost flat ground gently sloping either towards the plains in the south or towards the Doon valley in the north. Soil is generally dry poor, alluvial or sandy loam. Floristically *Shorea robusta* is the predominant species in Rajaji National Park. At several places almost pure stands of sal are found with *Mallotus philippensis* being the dominant understory along with *Ehretia laevis* and *Kydia calycina.* At places *Mallotus* is so dense that there is hardly any ground flora. Other tree species occurring in association with sal is *Lagerstroemia parviflora.* Several other species of minor occurrence include, *Bauhinia malabarica, Dalbergia sissoo, Cassia fistula, Ficus* sp., *Gardenia turgida Wrightia arborea, Aegle marmelos, Bauhinia purpurea* and *Butea monosperma* etc. Plant species occurring at shrub level include, *Mallotus philippensis, Holarrhena pubescens Adhatoda zeylanica, Ziziphus oenoplia* and *Lantana camara.*

2.7.5 Plantation

Prior to the declaration of the area as National Park, valuable timber trees were removed as a part of silviculture operations and forest management practices. Such areas were replaced by either monoculture or mixed plantations. Mostly plantations were raised on flat ground, however there are a few places on gentle slopes where small patches of plantation were also raised. These patches are quite different from the natural vegetation and form a new vegetation type. There are pure stands of *Ailanthus excelsa* and *Tectona grandis* plantations. In most plantations of *Ailanthus*, there is a thick undergrowth of *Lantana camara* while plantations of *Tectona* are mostly devoid of undergrowth. Mixed plantations of *Acacia catechu* and *Dalbergia sissoo* do exist at several places. Other species planted in mixed plantation areas are *Kydia calycina, Albizia lebbeck, Haplophragma* sp., and *Bombax ceiba.*

2.7.6 Weeds

The common perennial weeds are *Adhatoda zeylanica*, *Lantana camara*, *Calotropis* procera, and *Colebrookia oppositifolia. Adhatoda zeylanica* grows in shady moist areas and forms thick undergrowth in miscellaneous forests. *Lantana camara* is widely distributed on flat terrain and gentle slopes. At places, *Lantana* cover is so thick that it does not allow anything else to grow. The natural regeneration of woody species is poor in such areas and is one of the causes of habitat degradation. The common annual weeds are *Cassia tora, Parthenium histerphorus, Ageratum conyzoides* and *Cannabis sativa* etc.

2.8 Fauna of the Rajaji National Park

2.8.1 Mammals

A total of 49 species of mammals are known to occur in Rajaji National Park. I, however, have recorded only 23 species mainly of large and medium size mammals. Most noteworthy are the records of Indian Dhole (*Cuon alpinus*) and Indian wolf (*Canis lupus*). Both these species were recorded in Rajaji Sanctuary. Two individuals of Indian Dhole were first seen in Beribara area and then one individual in

Dholkhand Rau. A single individual of Indian wolf was seen near the southern boundary of the Rajaji Sanctuary in Ganjarban forest block of Dholkhand forest range. Jackal (*Canis aureus*) is a common species present throughout the Park. The Indian fox (*Vulpus begalensis*) do occur in the area but not very common.

The common leopard (*Panthera pardus*) was seen on few occasions in Rajaji as well as in Chilla area while tiger (*Panthera tigris*) was seen only once during the period of study. However, both these species have good populations. Scats and pug marks of tiger were frequently encountered in Dholkhand, Beribara, Gholna and Mohund forest blocks. Among the small cats *Felis bengalensis, F. viverrina* and *F. chaus* were also seen at few occasions. The small Indian civet (*Viverricula indica*) was also observed but it is difficult to put any guess about its population status and the same is true for yellow throated martin (*Martes flavigula*).

Among the ungulates the most common species is Cheetal (*Cervus axis*), mostly confined to the flat terrain of the park. Groups of Cheetal, ranging from few animals to more than 20 can be observed all along the forest roads. During the night, they congregate and form large groups near the human habitations either in the vicinity of Gujjar settlements or establishments of forest department. Sambar (*Cervus unicolor*) are mostly confined to the hill slopes and remain single or in small groups of two to three while the Barking deer (*Muntiacus muntjack*) occupy lower slopes and valleys. The sole representative of the goat antelope is Goral (*Nemorhaedus goral*), found on hill tops and steep slopes. Goral were regularly observed in Dholkhand and Mohund forest blocks. Nilgai (*Boselaphus tragocamelus*) inhabit southern boundary of the National Park towards the plains near cultivation and human habitation. *Sus scrofa* is another common ungulate found all over the area in good numbers.

A few species of small mammals such as the common mangoose (*Herpestes edwardsi*), Indian porcupine (*Hystrics indica*) and Indian hare (*Lepus nigricollis*) were seen regularly in the Park. Most of the sightings of common mangoose and Indian hare were restricted to flat terrain while porcupine were seen on flat terrain as well as on gentle hill slopes and valleys.

Troops of Rhesus macaque (*Macaca mulata*) ranging from few animals to as large as of about hundred individuals were encountered all through the Park but they were more frequently found in miscellaneous forests and scrub vegetation. The population is healthy as most troops consist of all age groups with many young ones. The langur (*Presbytis entellus*) also inhabit the area in good numbers, but the population is small as compared to Rhesus macaque.

2.8.2 Birds

The avifauna of Rajaji National Park is rich. Pandey *et al.* (1994), have compiled a list of 312 species, out of these 144 species are residents, 89 are migrants, 53 are altitudinal migrants and eight species are local migrant. The status of 18 species is not known. I did not make much efforts in compiling a checklist of bird species but casually recorded whenever time permitted after the routine field work. I recorded only 88 species mainly in Rajaji Sanctuary.

2.8.3 Reptiles

The reptilian fauna of the Park includes 9 species of lizards belonging to 5 families and 28 species of snakes belonging to 11 families as reported by Anonymous (1995). The species of lizards reported from the park are *Varanus begalensis, Hemidactylus flaviviridis, H. brooki, Calotes versicolor, Agama tuberculata, Mabuya macularia, M. dissimilis*, *Riopa punctata* and *Ophiosops jerdoni.*

Out of the total 28 species of snakes reported from the park only four species were seen. These were Common Rat Snake *Ptyas mucosus*, Common Cobra, *Naja Naja*, Indian Python *Python molurus* and Common Wolf Snake *Lycodon aulicus*. Other species of snakes reportedly occurring in Rajaji National Park include Common Blind Snake *Ramphotyphlops braminus,* Large Blind Snake *Typhlops diardi*, John's Sand Boa *Eryx johni*, Twin-Spotted Wolf Snake *Lycodon jara* and Buff-Striped Keelback *Amphiesma stolata* etc.

2.9 The Water distribution

There are three natural perennial sources of water in the area the Ganga, the Rawasan and the Song rivers. As all these rivers flow along the boundaries, the problem of water supply in rest of the park area remains precarious. There are no perennial water source at the southern slopes of the Shivalik. The main sources of water, in this stretch are hill streams coming through 'Rau'. Most of these streams dry up during the months of March and April with water availability being limited to small and widely scattered pools and pits in dry Rau beds.

To reduce the severity of water, Forest Department constructs few temporary saucer shaped waterholes. Mostly such water bodies are confined to the areas near the road and on flat ground where water can easily be supplied by water tankers. During summer, these water bodies are of great help in providing respite to wild animals.

2.10 Forest fire

During summers the forest fire is a common phenomenon in the Shivalik. In spite of the efforts of the forest department in taking preventive measures to reduce chances of fire, there are incidences of fire on regular basis. Deciduous nature of vegetation coupled with drying up of annuals during summers allows accumulating enough fuel on the forest floor, a little negligence on the part of people sparks of the fire. Mostly the fire is an outcome of human activities. Sometime it is due to throwing of cigarette or Bidi buds and sometime it is also intentional when pastoralists living in the forest put on fire in order to get early flush of grasses for their cattle. Intensity of fire depends upon the climatic conditions especially temperature, wind speed and direction. When the occurrence of fire is in hilly areas, it is more devastating, in the sense that it spreads quickly and engulfs large area and is difficult to control as compare if it occurs in valleys or in plains. Fire in Rajaji is one of the management problems as it destroys ground flora and fauna more or less completely, enhances the chance of soil erosion, hampers recruitment of new forest crop and encourages spread of weeds like *Lantana*.

2.11 Human interference

There are three communities of people living inside the park viz- the Gujjar, the Taungya and the Gothia. Gujjar are transhumant pastoralist originally belonging to Jammu and Kashmir. It is believed that more than a century ago the Gujjar of Jammu and Kashmir started moving into the Shivalik hills east of river Yamuna where they raised buffaloes and practiced transhumant pastoralism. They use to spend about six months, between October and April in the Shivalik and the rest of the months in high altitude alpine pastures of the Himalayas and in migration between the two areas. Usually the migration between the summer and winter grazing zones use to take three months. This traditional life style of the Gujjar was ecologically sustainable, as the forest of Shivalik use to get respite from the grazing pressure during the monsoon and the alpine pastures during the summer, the main growing seasons of vegetation, thereby accumulating new biomass and maintaining diversity through regeneration. The migration between alpine pastures and Shivalik was beneficial to the Gujjar and their cattle, providing an opportunity to make use of two rich ecosystems during seasons of high productivity. This practice of transhumant pastoralism continued until 1985 when Forest Department of the then Uttar Pradesh declared a part of the Shivalik forest as Rajaji National Park. The Forest Department then initiated the process of settling Gujjar out of the Park in order to follow the norms of a national park in the spirit of the "Wildlife (Protection) Act 1972". As per the existing laws, no human habitation is allowed inside a national park. In 1986, fearing the danger of denying entry into the Rajaji National Park on their return from alpine pastures, the Gujjar stopped migrating during summer and opposed the resettlement plan of the forest department as it was completely changing their life style from transhumant pastoralist to village dwellers. As a consequence, the Gujjar became permanent residents of the Rajaji National Park.

There are about 1390 families with a human population of 5000 and equal number of cattle, dotted in various settlements all over the park. Mostly a single family owns a settlement locally called as Dera along some permanent water source amidst the forest. Prior to the declaration of Rajaji National Park, each family of the Gujjar was allotted a portion of forest around its Dera for grazing its cattle on a nominal fee. This was done on a rotational basis; some areas of the forest were always kept closed for the Gujjar, giving forest enough time to rejuvenate from previous year's grazing. However, this practice has also discontinued now, as the forest department has stopped issuing permits under the new rules of national parks. This is causing a major drain on the resources of the national park, as Gujjar are totally dependent on the forest for their needs of fodder, fuelwood, grasses and timber for construction of their Dera.

The change in migratory pattern has had a number of environmental consequences as well. When the vegetation grows during the rainy season, palatable plants and grasses come under heavy grazing pressure, especially on the lower slopes and plains. Unpalatable weed species such as *Adhatoda zeylanica, Cassia tora, Lantana camera* and *Parthernium hysterosporus* grow unfettered and progressively usurp the growing space below and above the ground. Forage does not accumulate under these conditions, and there is sudden scarcity of fodder once the rainy season is over. This has resulted in indiscriminate and excessive lopping of trees causing alteration in natural pattern of flowering, fruiting as well as adversely affecting the regeneration of fodder trees. Opening of canopy coupled with grazing of ground layer is encouraging growth of weeds and thus is in the process of changing forest composition.

The Taungya were employed as shifting cultivators by the forest department for raising forest plantation and were allowed to grow crops in those areas till the plantation needed protection. Normally they were allowed cultivation for three years after raising plantation in an area and then were moved to new area where plantations were planned. There are about 700 Taungya in about 200 families living in four Taungya villages. These Taungya villages may be marked as outside the Rajaji National Park but for all practical purposes, they depend upon forests of the park. Taungya do own cattle those also graze inside the park and collect Bhabar grass for making rope called Baan.

There are 47 families of Gothia with a human population of about 250 and a cattle population of 300 inhabiting different parts of the national park in scattered settlements. Gothia were rehabilitated in Rajaji some time in 1975 when their native place was covered under a land slide. They graze animals, collect fodder, and fuel wood from the park.

Apart from the Gujjar, the Taungya and the Gothia, there are several villages around the national park those are dependent on the forest resources of the park. Though prohibited by law, the villagers still graze their cattle at periphery of the park. They are also dependent on the forests of the park for their needs of fuelwood, timber and thatch grass etc.

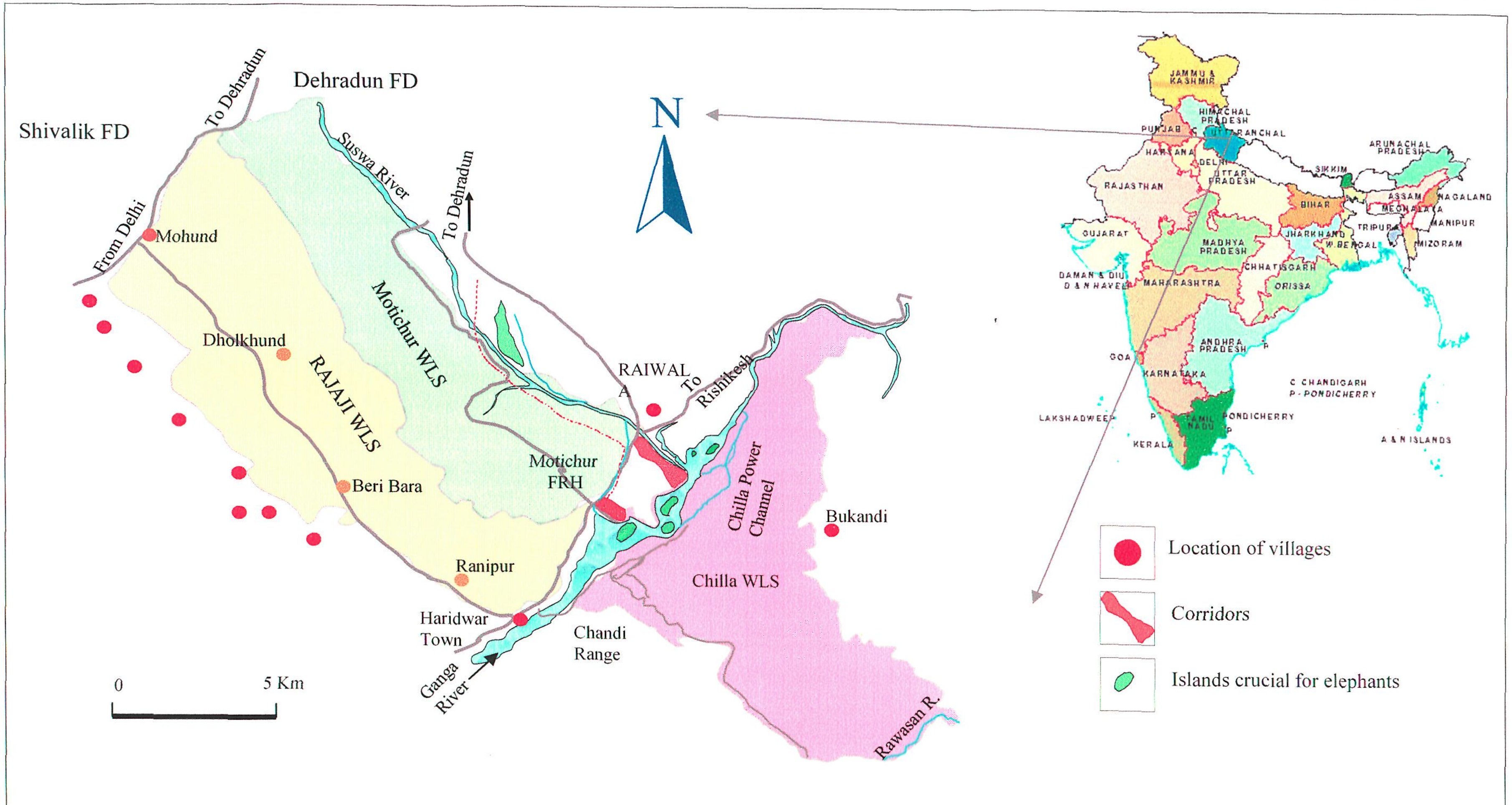


Fig. 2.1 Location map of Rajaji National Park

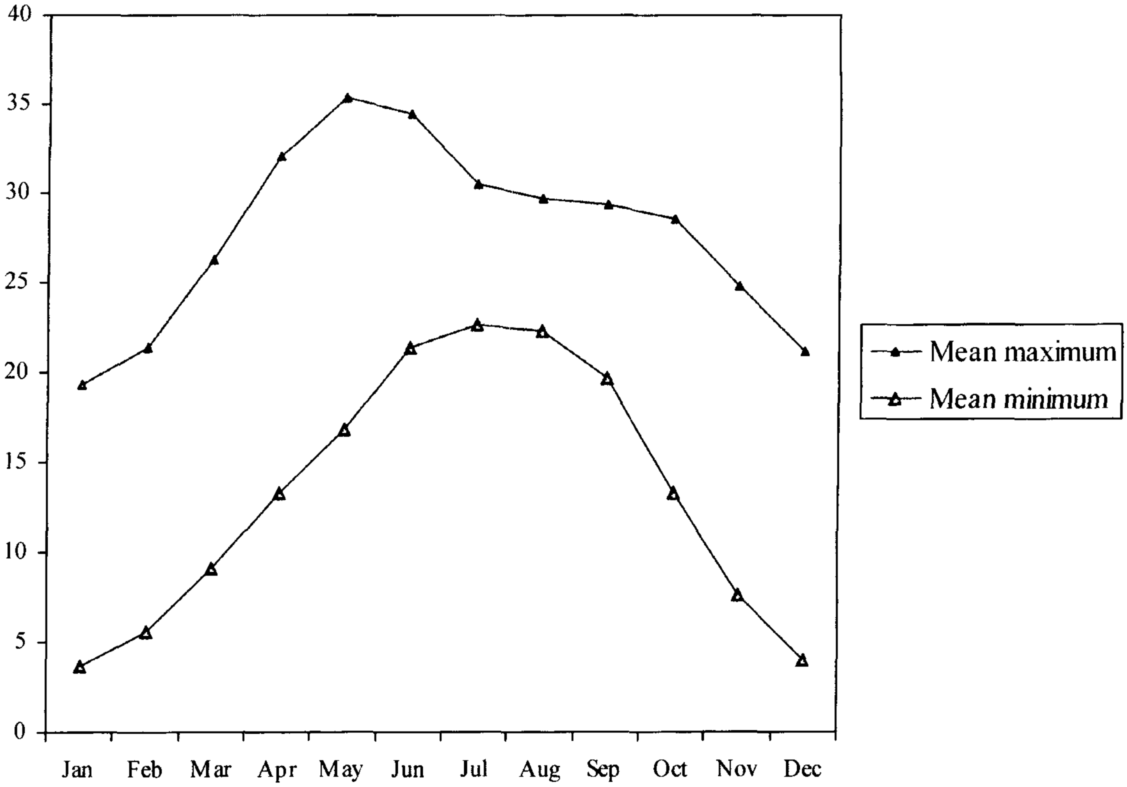


Fig. 2.2 Mean monthly maximum and minimum temperature values (degree Celsius) in the study area.

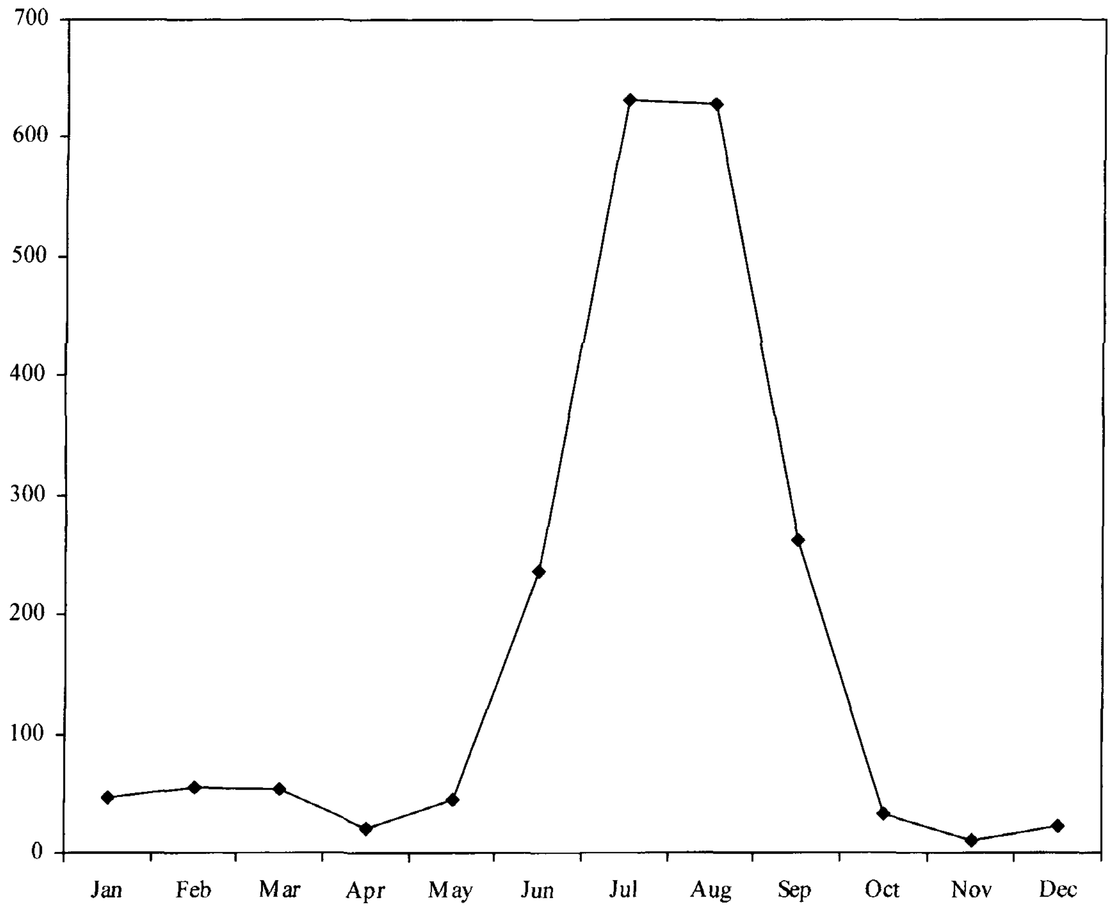


Fig. 2.3 Mean monthly rainfall (in mm) values in the study area.

Chapter 3: Current status and distribution of the Asian elephants

3.1 Elephant distribution

The Asian elephant (*Elephas maximus*) once ranged over a vast geographical area from the Tigris-Euphrates in west Asia eastward to Indian sub-continent as well as south and southeast Asia through Persia including the islands of Java, Sumatra, Borneo and Sri Lanka, and to the north into China as far as Yagste Kiang. Its range, however, has considerably shrunk and presently the species is distributed in fragmented populations, surviving in China, Bangladesh, India, Nepal, Bhutan, Myanmar, Sri Lanka, Indonesia, Kampuchea, Laos, Malaysia, Thailand and Vietnam (Fig. 3.1).

Olivier (1978) has reviewed in detail the past and present distribution of Asian elephants. Later, Sukumar (1985) also documented the same with special reference to the Indian subcontinent. Recently, Daniel (1998) documented a detailed account of historic presence and current distribution of elephant populations within the limits of Indian territory. All these accounts are unanimous as far as past and present distribution of elephants are concern and I therefore do not wish to venture further on the subject, which has already been elaborately covered by the earlier workers. In this chapter, I have reviewed the available information on the current status and distribution of the Asian elephant populations in range countries.

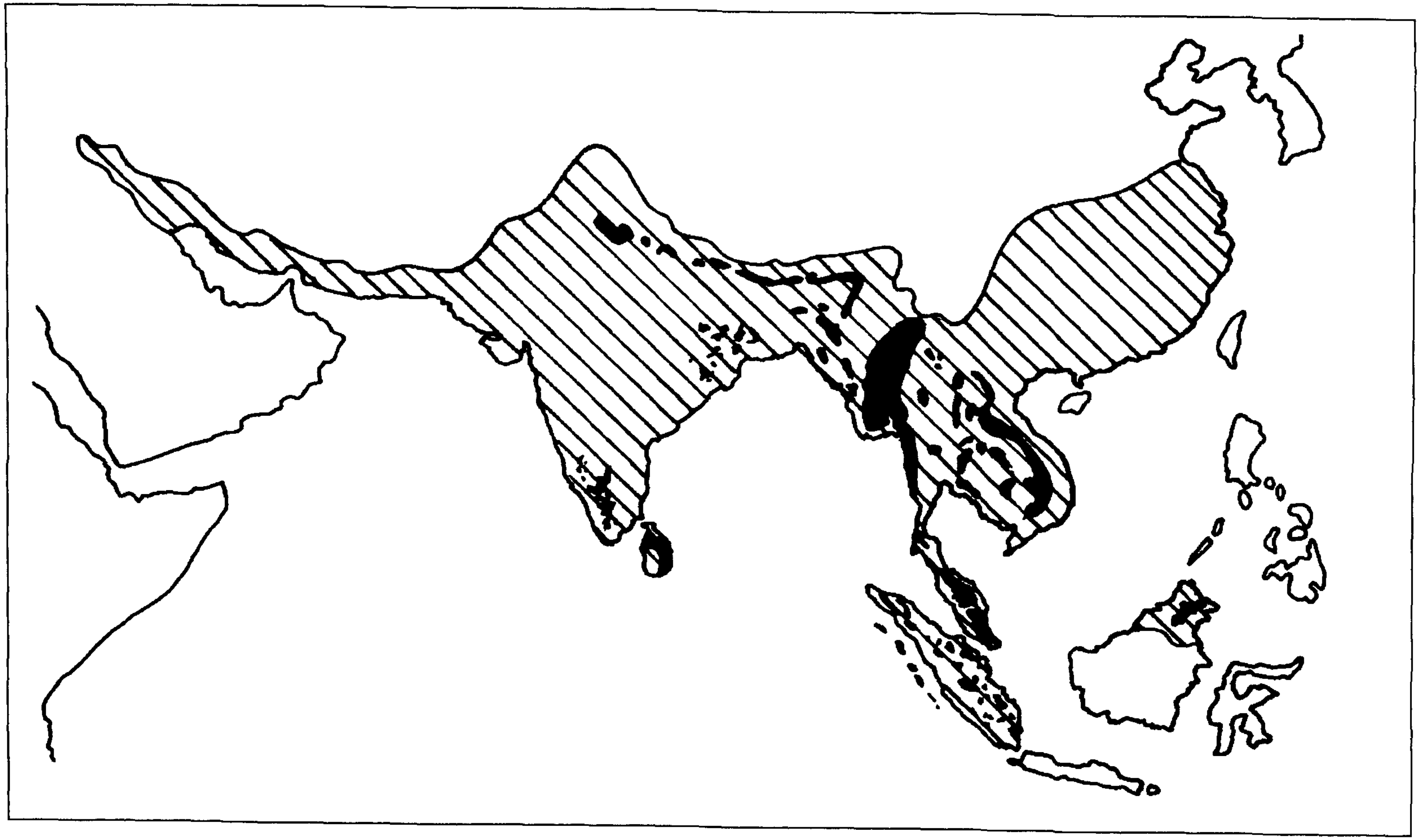


Fig. 3.1 Past and present distribution of the Asian elephants in range countries.

3.2 Population size

Olivier (1978), for the first time estimated the population size of Asian elephants in range countries and arrived at a minimum figure of 28,000 and a maximum of 42,000 individuals. Later, Sukumar (1985) reviewed the status of elephant population and estimated total numbers of Asian elephants between 36,525 and 54,025. In 1989, he updated his earlier estimate of 1985 and predicted the population size of Asian elephants between 35,390 and 56,045. The subsequent revision in 1992, by incorporating recent information on the population size from southern and northwest India, Laos, Kampuchea and Vietnam has tallied the elephant numbers between 37,815 and 59,980. The WWF-International and the IUCN Asian Elephant Specialist Group in 1996 estimated the total population of Asian elephants between 33,600 and 47,835. Since all these estimates are based on the efforts made by various workers at different times therefore a detailed appraisal is necessary in order to understand the population size and problems associated with it. Following section on population size in range countries is mainly based on the available literature.

3.2.1 India

The Asian elephant in India occurs in four distinct geographical regions; the north-western population inhabiting Shivalik Hills and Terai of Uttar Pradesh, the north-eastern population occupying Himalayan and sub-Himalayan foothills and the Terai in the north-eastern states from north Bengal to Manipur. The central Indian population distributed in the states of Bihar, Orissa and part of West Bengal while the south Indian population of elephants distributed over an area in the states of Karnataka, Kerala and Tamil Nadu. However, Sukumar (1985) and Daniel (1995) have advocated that there are two elephant populations in south India; one to the north and another to the south of Palghat Gap (Fig. 3.2) while others consider them as sub-populations rather than two distinct populations.

Probably first ever population estimate of Indian elephants was reported by Gee (1964) giving a figure of 7,000 in the wild and it was followed by Olivier (1978) with a total number ranging between 9,950 and 15,050. Olivier underestimated the population inhabiting north-east and southern India mainly due to the lack of sufficient information on these populations. Sukumar (1985), however, estimated southern population in a more realistic manner than ever before and his last update in 1992 had put the elephant numbers between 8,525 and 11,930, which are undoubtedly satisfactory.

A great deal of efforts has gone in assessing population size of north-eastern elephants, however, uncertainty still shrouds as far as elephant numbers are concern. It is mainly due to unfriendly weather conditions, vastness of the area, difficult terrain and unstable socio-political situations and hence all estimates barring a few areas where surveys have been conducted in recent times are merely guesses.

Elephant populations of central and north-west India have been assessed with relatively higher degree of precision mainly by the efforts of Central Indian Task Force of the Asian Elephant Specialist Group (Shahi, 1980; Shahi & Chowdhury, 1986) and later by the Datye & Bhagwat (1995) and Singh (1995). The estimated population of elephants in central India is between 1,768 and 1,873.

Champion (1927) had assessed the size of north-west population for the first time. After a gap of 38 years, V.B. Singh in 1966 had organised a census of elephant population simultaneously in nine forest divisions of the then Uttar Pradesh (U.P.) and since then it has been regularly monitored at an interval of about ten years

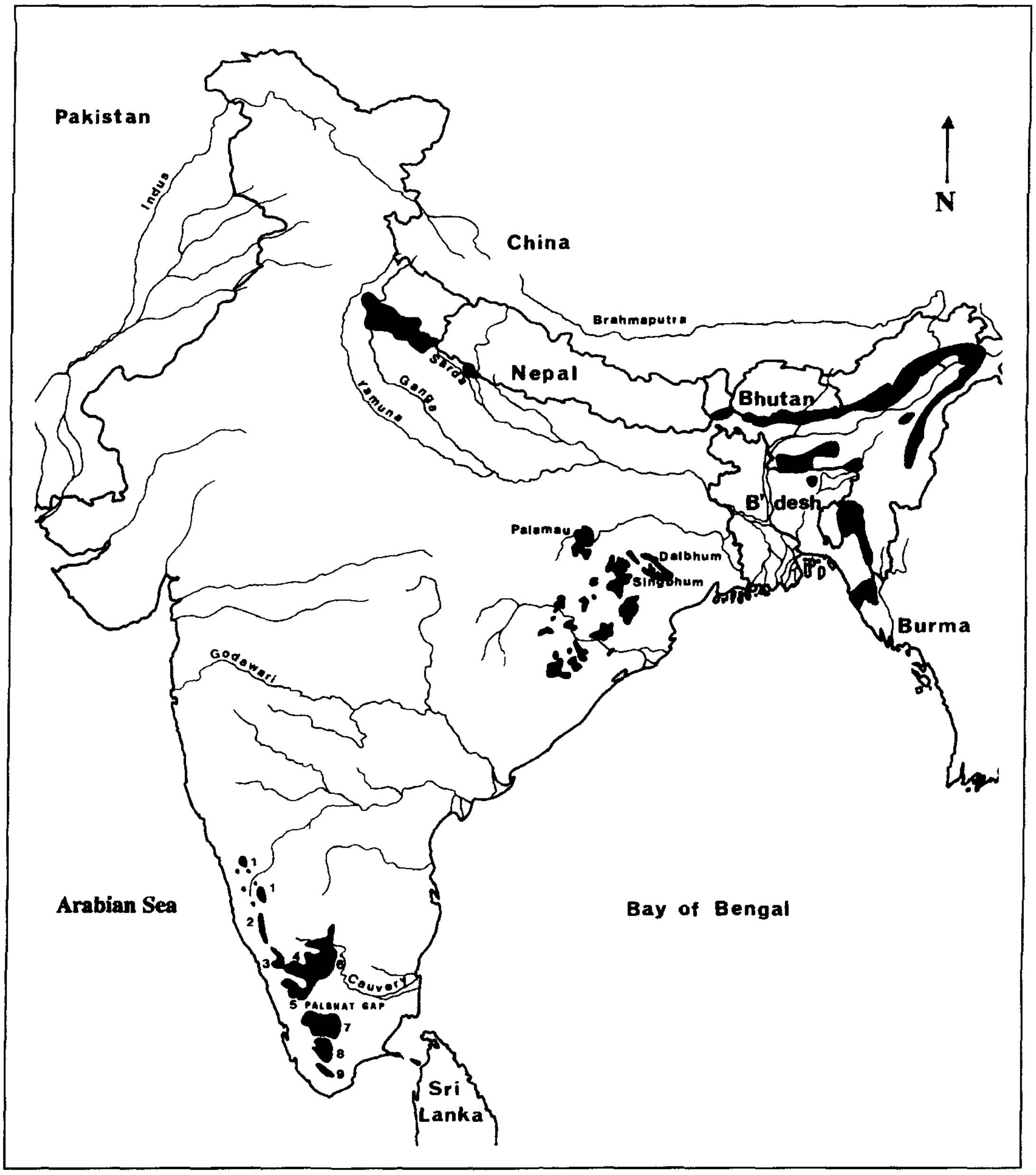


Fig. 3.2 Distribution of the Asian elephants in India.

(Singh, 1969; 1978; 1986 and Singh, 1995). The estimated population of north-west India is between 877 and 1,069.

3.2.2 Bangladesh

Elephant population inhabiting Bangladesh is comprised of small fragmented seven sub-groups, five of them are in Chittagong hills and are more or less resident in that area (Fig. 3.3). Part of the elephant population in Bangladesh is migratory to India and Burma. Other small groups are found in three protected areas; namely the Himchari National Park, the Mainimukh and the Pablakhali Wildlife Sanctuaries. The estimated population is between 200 and 350 elephants (Sukumar, 1992). Earlier estimate by Khan (1980) was of 200 elephants while Gittins and Akonda (1982) gave a figure between 282 and 348.

3.2.3 Bhutan

Elephants in Bhutan survive in small fragmented populations in protected areas along the border with India (Fig. 3.4). The Royal Manas National Park is the only protected area large enough to hold sizeable resident population. Traditionally, elephants use to move seasonally between the Himalayan foothills of Bhutan to the Terai grasslands of India. It is thought that as many as 3,000 elephants spend the summer in Bhutan, most of which migrate to Phibsoo Wildlife Sanctuary, Khaling, and the Royal Manas NPs, which is contiguous with the Manas Tiger Reserve in India. The estimated population of wild elephants in Bhutan in 1996 was 60 to 150. However, recent estimates are between 2,000 and 3,000 (Jackson & Kemf, 1996) This sharp increase does not represent a drastic rise in numbers but is a result of impaired movement of elephants between traditionally seasonal ranges in India and Bhutan. Large scale movement of elephants in this region is no longer possible mainly due to the establishment of human settlements and other developmental

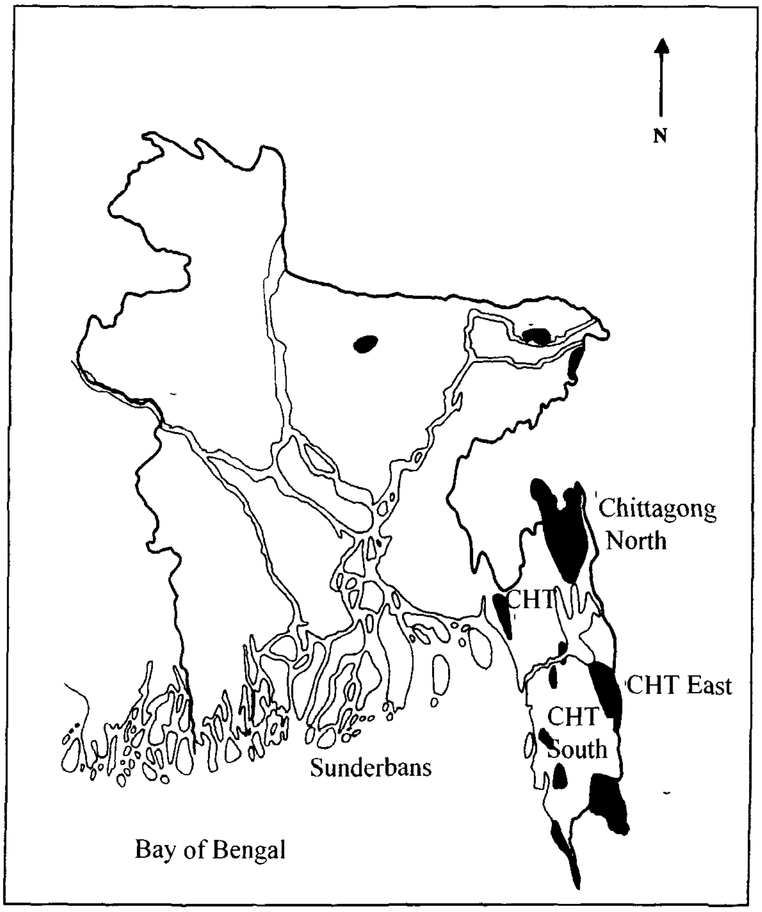


Fig. 3.3 Distribution of the Asian elephants in Bangladesh.

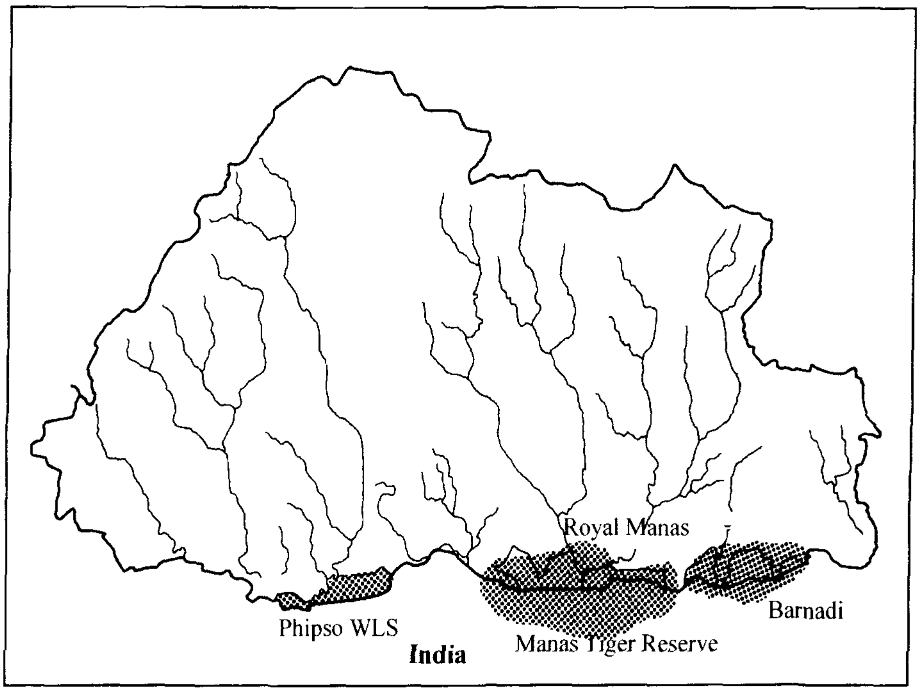


Fig. 3.4 Distribution of the Asian elephants in Bhutan.

activities along the Indo-Bhutan boarder, however, occasional movements of a few or solitary individuals can not be ruled out.

3.2.4 Nepal

Olivier (1978) estimated a population of 50 elephants in Nepal while Mishra (1980) gave a figure of 22-25 and Santiapillai and Jackson (1990) enumerated the elephant numbers between 24 and 34. A team of Scientific Exploration Society conducted a survey during March 2001 in Bardia (western Nepal) and counted 45 elephants. Probably Bardia is the only refuge of resident elephant population in Nepal. Other small populations inhabiting the Terai of Nepal along the Indian boarder (Fig. 3.5) until few decades back have either been lost to poachers or migrated to Indian territory due to the extensive clearance of forests for cultivation by the Nepal government. The group of elephants migrating between Nepal and Dudhwa National Park in U.P. till 1990 is now resident of Dudhwa. Another group of about 20-30 elephants has recently (in 2001) taken refuge in Katerniaghat Wildlife Sanctuary and yet another group of 15-20 elephants has occupied reserved forest of Pilibhit Division in U.P. They do some time wander in Nepal's territory mainly because of their migratory habits along the traditional routes, but non-availability of suitable habitat there is forcing them to remain in the Indian side more or less permanently.

3.2.5 Myanmar

The second largest population of elephants inhabits Myanmar, spread over a vast area of about 3,85,500 Km^2 almost through out the forested area of the country barring high hilly region in the north and dry zone in the centre (Fig. 3.6). Elephant population in Myanmar was assessed more regularly than other populations elsewhere as perceived from the account of Olivier (1987). He mentioned a series of population estimates carried out or documented by various workers and according to

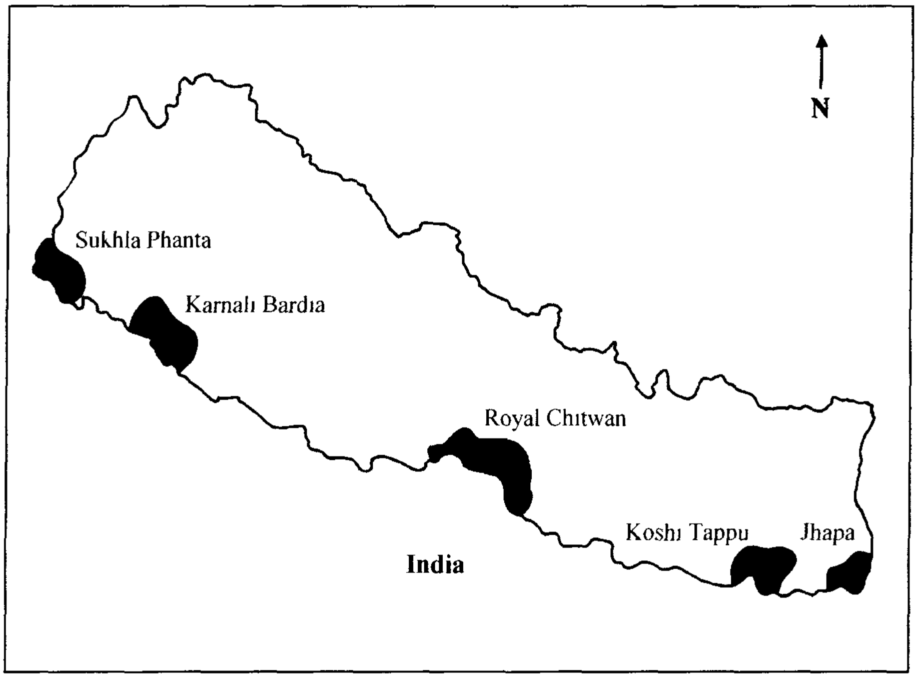


Fig. 3.5 Distribution of the Asian elephants in Nepal.

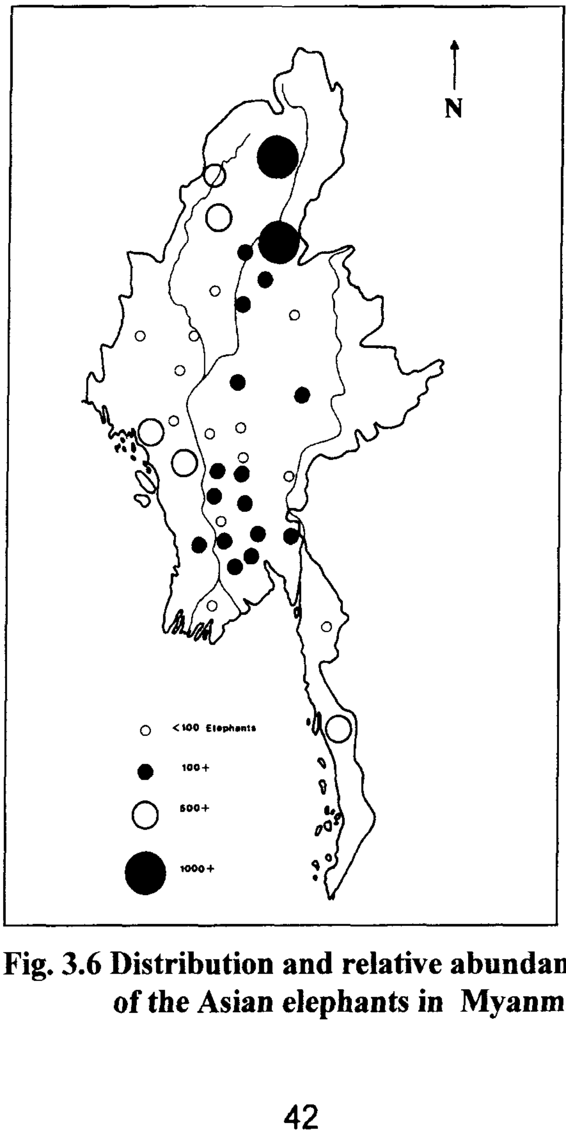


Fig. 3.6 Distribution and relative abundance of the Asian elephants in Myanmar.

his account, Peacock (1933) estimated population size of about 3,000 elephants for the whole of Myanmar. Later estimates gave a figure of about 10,000 elephants in 1935 of which 8,500 from Burma and 1,500 from the Federated Shan States while Smith (1944) reported only 5,000 and U Tun Yin (1959) estimated 6,250 individuals and it was followed by a figure of 6,000 in 1950. Subsequent estimates in 1962 put forth a figure of 6,500 and in 1974, the population was assessed as about 8,500 while the figures in 1977 came down to 5000. Olivier (1978) assessed the population size as 5000, while Caughley (1980) estimated the population size of about 3000 elephants. About a decade later, Sukumar (1992) opined that all estimates about the population size of Myanmar are subjective, not even a single population has so far been objectively assessed and hence almost all figures are under estimates considering the vastness of available habitat. He further argued that even if elephants were to exist at very low densities (0.1/ km^2), about 10,000 elephant might still survive over the forested area of Myanmar (about 1,00,000 km^2 in extent). Sukumar's opinion about the population size appears to be optimistic considering the history of elephant capture and killing in Myanmar during the last century. Olivier (1987) has mentioned that a total of 7,000 elephants were captured between 1910 and 1927 and 1,286 between 1935 and 1941. The capture of elephants continued and on an average about 165 individuals per annum were captured between 1962 and 1973. He further mentioned that the level of capturing though reduced in 1970s but continued. Additionally, poaching for ivory is on the rise, which is further reducing elephant population. The latest estimate of 4,150 elephants as reported by Martin & Vigne (1997) indicates a declining trend in elephant population.

3.2.6 China

Today, the elephant population in China occurs in the Xishuangbanna Dai Autonomous Prefecture, southern Yunnan province bordering Laos and Myanmar (Fig. 3.7). First detailed information on the population status and distribution in China was collected through field surveys conducted between 1990 and 1991 and based on these surveys, Santiapillai *et al.* (1991) estimated elephant numbers less than 500. Olivier (1978), however, guessed a population of 100 elephants and Sukumar (1992) gave a figure of 100-230 elephants. According to Xiang & Santiapillai (1995) there are two main strongholds of elephants; the Mengyang sub-reserve supporting about 100-120 elephants and Shangyong sub-reserve inhabited by about 130-150 elephants. Another area holding about 100 elephants is the riparian forest along the Xiao Hei River while few individuals are known to occur along the Laotian border, which regularly move between China and Laos. Thus, the total population is between 350 and 500 elephants.

3.2.7 Thailand

Elephants in Thailand are patchily distributed over the remaining forested hill tract in four sub-populations (Fig. 3.8). About half of the total elephant population inhabits western portion of the country bordering Myanmar, while other small discrete groups inhabit Petchabun and Dangrek mountain ranges and the region between Ranong and Trang in the peninsula (Sukumar, 1992).

Olivier (1978) estimated the population size to be approximately 2500-4500 elephants. Sukumar (1992) also estimated more or less the same numbers; between 2925 and 4550. However, the estimates given were much lower than the earlier estimates and the total population size was estimated between 750 and 1,055 only. Later, Jackson & Kemf (1996) provided an estimate of 1500-3000

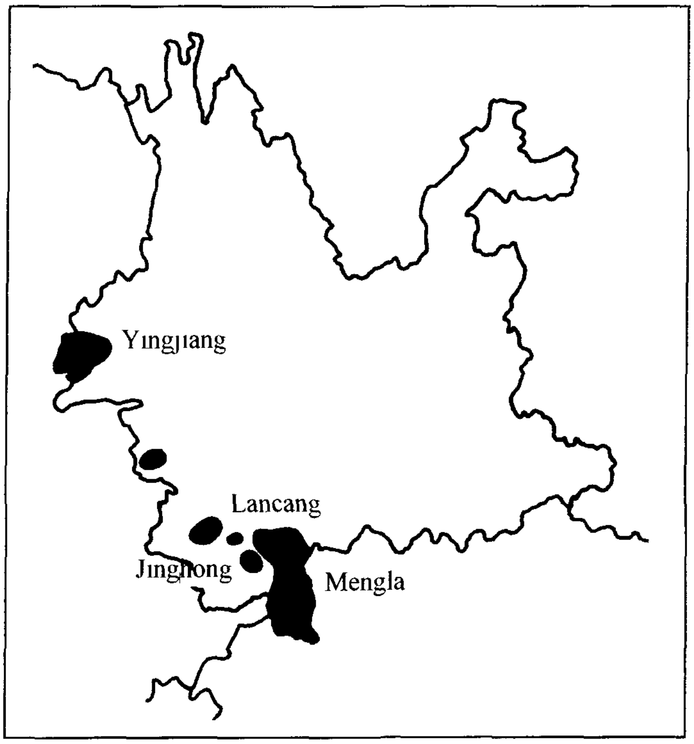


Fig. 3.7 Elephant conservation areas in Yunnan Province of China.

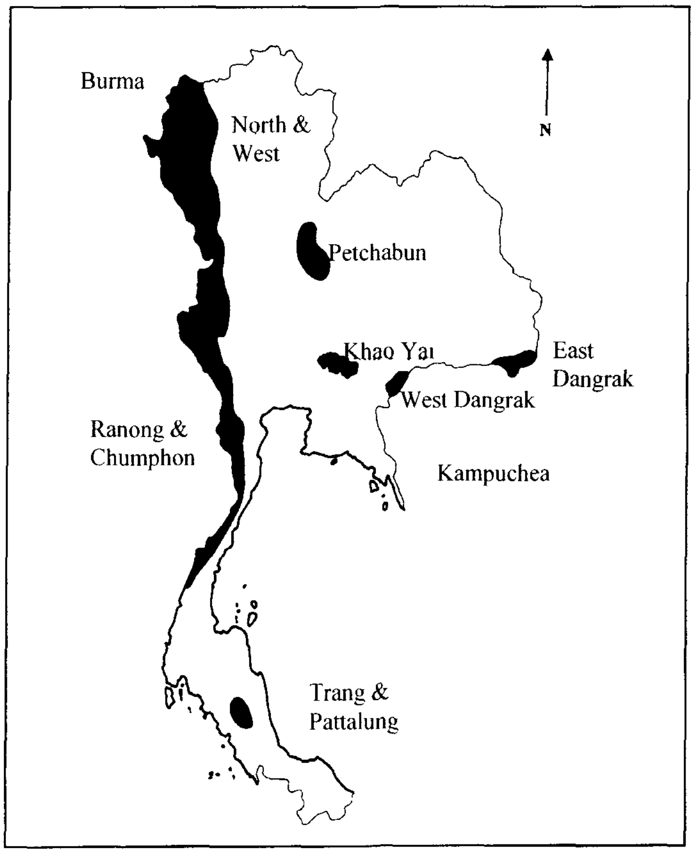


Fig. 3.8 Distribution of the Asian Elephants in Thailand.

elephants. The variance in elephant numbers as discernible from various estimates can not be treated as fluctuations in the population but is a result of inconsistency in estimating the population size. Only few populations inhabiting protected areas were properly surveyed while the rest are yet to be systematically assessed. Elephant population in Thailand, however, is declining as indicated by the fact that the numbers of domesticated elephants have reduced from about 13,000 in 1950 to less than 500 in 1990. McNeely in 1975 (cited in Olivier, 1978) stated that the elephant population in Thailand are becoming reduced so much so that the local people now have to get their domestic elephants from Cambodia. The reasons attributed to the decline in elephant numbers are extensive clearance of lowland- forested areas and hunting pressure.

3.2.8 Laos

Limited information on the status and distribution of elephant population of this country is available. Venevongphet (1995), based on a reconnaissance survey of Laos indicated for the first time that elephants are found in 13 of the country's 16 provinces. The largest population is in Sayabour while other sizable populations inhabit Thakek and Champasak provinces (Fig. 3.9). Till the time of compilation of this dissertation, no information on the population size based on the proper surveys is available. However, Santiapillai (1987) based on questionnaire survey indicated a population of about 2,000 elephants in Laos followed by the reported estimation of Jackson and Kemf (1996) that tally the numbers between 2,000 and 4,000 but with uncertainty. The population of elephants in Laos is on the declining trend as opined by Venevongphet (1995). The main reason of population decline seems to be magnitudinal decrease in the forest cover. As per an estimate about 70,000 ha forest was being lost each year during 1982-1989.

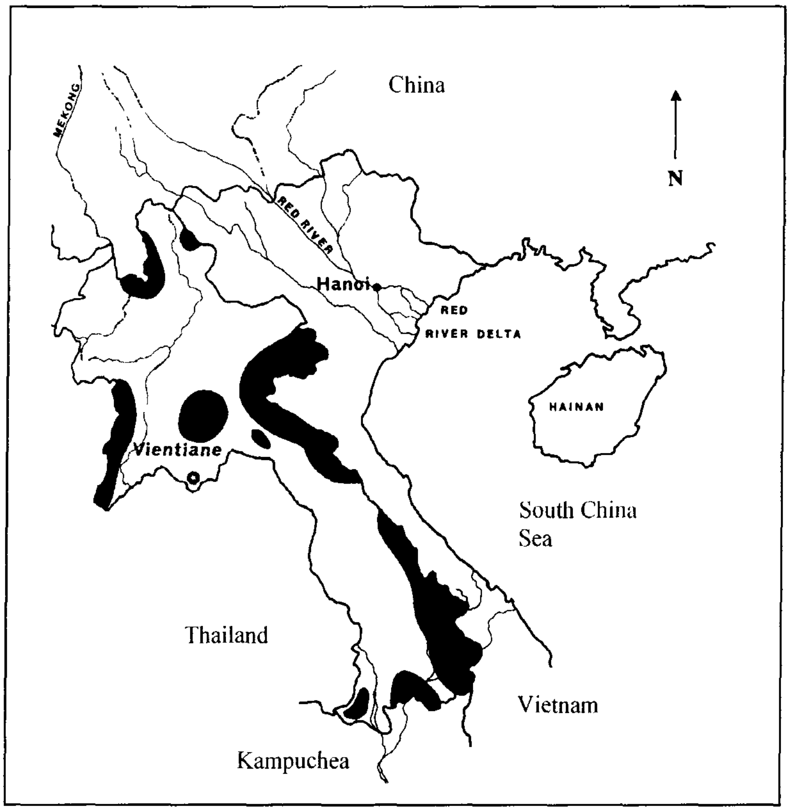


Fig. 3.9 Distribution of the Asian Elephants in Laos.

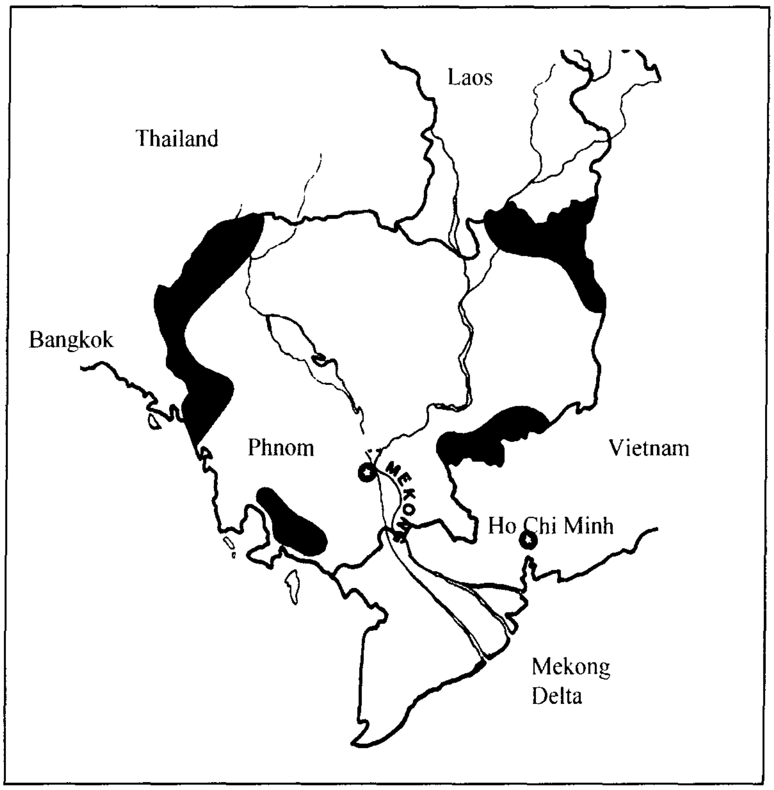


Fig. 3.10 Distribution of the Asian Elephants in Kampuchea.

3.2.9 Cambodia (Kampuchea)

Information on status and distribution of elephant populations is scanty. Political upheaval, insurgency and war in the recent past did not allow any one to assess the population status or any other studies on elephants. It is however, estimated that about 74,000 km^2 or 40% of geographical area of Cambodia is forested and elephants are found on the boarder with Vietnam and in the Dangrek range adjoining Thailand up to the Laotian border (Fig. 3.10). They are also found near southern coast in Cardamon and Elephant Mountains that is also considered as potential elephant habitat (Sukumar, 1992). The population estimates by Olivier (1978), Sukumar (1992) and more recently by Jackson and Kemf (1996) are educated guesses and do not represent true picture. It is believed that there are about 2,000 elephants in Cambodia. If this figure is somewhere near the actual numbers than it clearly shows a declining trend in population as earlier guess estimate of Pan Leang Chev (cited in Olivier, 1978) indicated a population of 10,000 elephants in 1969.

3.2.10 Vietnam

Elephants in Vietnam, today, survive in fragmented small populations in 14 protected areas located in Lai Chau province in the northwest along the Laotian boarder, Troung Son mountain range and Tay Nguyen plateau to Dong Nai province in the south (Fig. 3.11). The estimated population of elephants is between 500 and 700, of which about 300 are in various protected areas (Khoi, 1995). The largest elephant population (69 elephants) inhabits the Jok don Reserve located in Dak lak province. The Muong nhe, the Mom ray and the Vu Quang Reserves each has a population of 30 elephants. Elephant populations inhabiting rest of the 10 reserves are even smaller and between 10 and 25. The wellbeing and survival of elephant population in Vietnam needs management of protected areas and strict enforcement

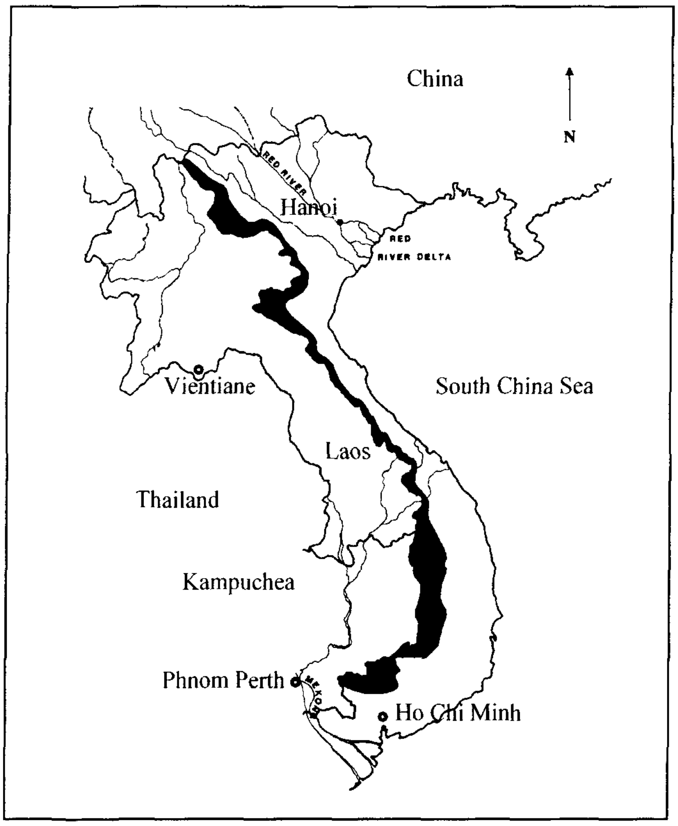


Fig. 3.11 Distribution of Asian Elephants in Vietnam.

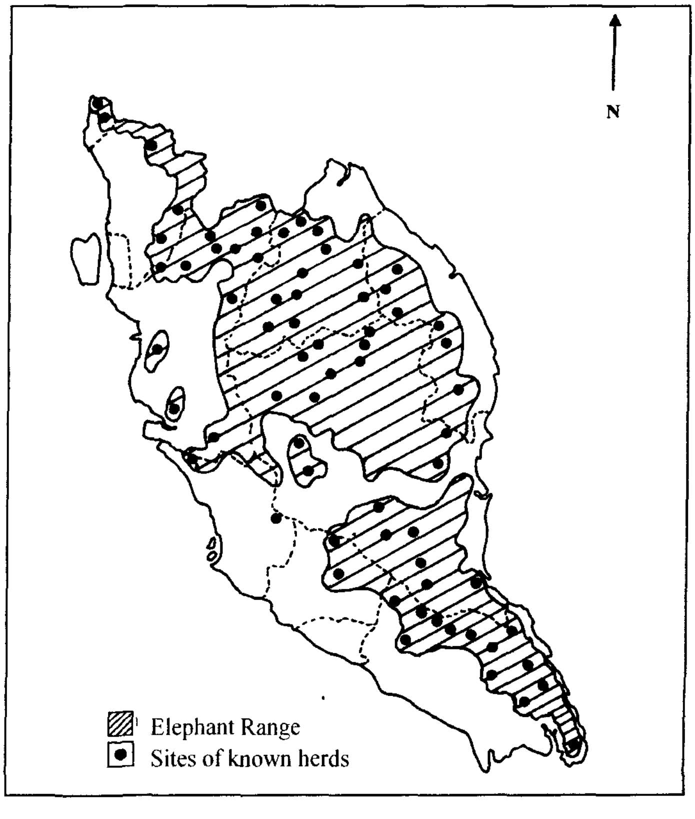


Fig. 3.12 Distribution of Asian Elephants in Peninsular Malaysia.

of conservation laws to curb poaching. Though, the data on past distribution and status of elephant population is not available but it is estimated that the population has declined by about 75 percent during last 25 years (Jackson & Kemf, 1996).

3.2.11 Malaysia

Elephants in peninsular Malaysia are found in small-scattered groups distributed over a wide area from north, bordering Thailand to the southern extreme of the country (Fig. 3.12). Systematic recording of elephant distribution in Malaysia had begun as early as 1960 when Foenander (1961) published the first map of elephant distribution. Medway (1965), for the first time published the population estimates of elephants and other animals based on the surveys carried out between 1960 and 1963. Since then several workers have carried out studies on the population status and distribution of elephants, notable among them are Stevens (1968), Khan bin Momin (1969; 1971 & 1977 a) and Olivier (1978). The numbers of elephants estimated by various workers have varied widely from about 600 to 6,000. The lower figure is based on the registration of known herds those came in contact and usually result in underestimation while the higher figure is a result of extrapolation from density estimates, which usually results in over estimation, may be rather optimistic (Olivier, 1978). The recent estimates suggest that the elephant population in peninsular Malaysia is about 800 to 1,000 (Jackson and Kemf, 1996).

3.2.12 Sri Lanka

Systematic documentation of elephant population in Sri Lanka was started in 1950's when Norris (1959) documented the status and distribution. Later workers such as McKay (1973), Hoffmann (1975) and Olivier (1978) did not notice much change in the distribution range, however, the Accelerated Mahaweli Ganga Development Programme initiated in 1979 has severely fragmented and reduced the elephant

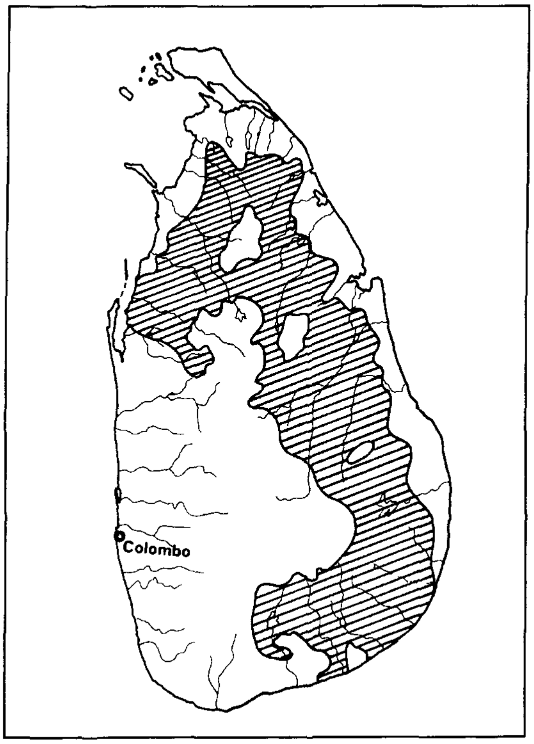


Fig. 3.13 Distribution of Asian Elephants in Sri Lanka.

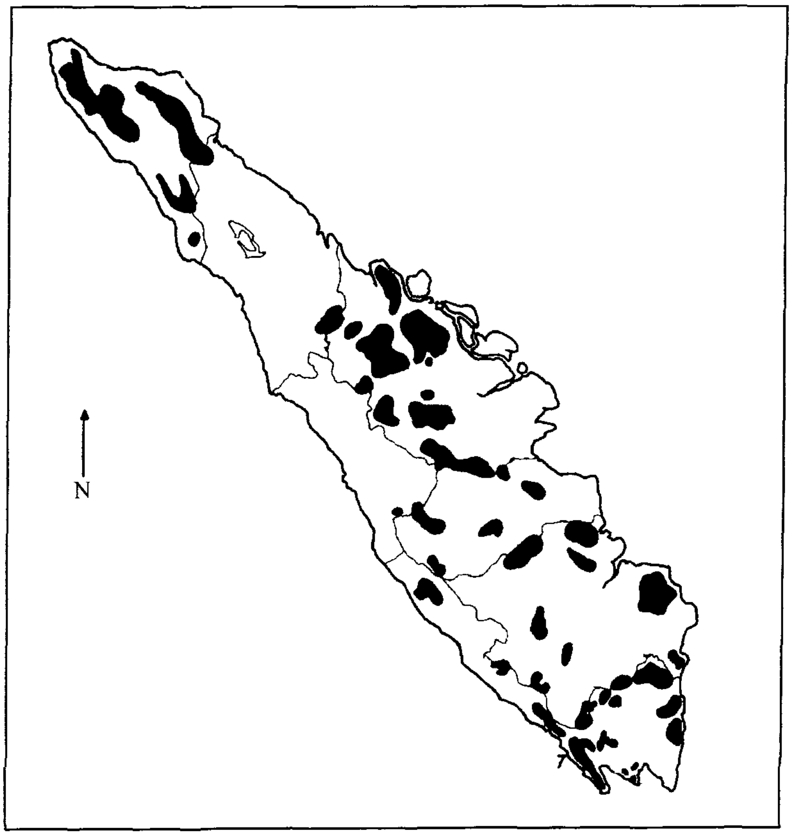


Fig. 3.14 Distribution of Asian Elephants in Sumatra.

habitat in Mahaweli Ganga basin holding a population of about 800 elephants prior to the launch of the Mahaweli project. Presently, elephant population in Sri Lanka can be considered in four regions; the northwest region, which includes Wilpattu National Park and its adjoining forest areas, the Northern Province, Mahaweli Ganga Basin, and the south-eastern region which includes Gal Oya and Ruhuna national parks, Yala Strict Nature Reserve and Amparai Sanctuary and their adjoining forest areas (Fig. 3.13).

Norris (1959), for the first time made an effort to estimate population size and he documented a total population of 1,500 though with the caution that more information was needed to arrive at a realistic figure. Mackay (1973), based on the surveys carried out in some areas gave a figure of 1,600 to 2,200 but concluded that the estimate is only a first approximation. Hoffmann (1975), opined that there are at least 4,000 elephants in Sri Lanka. Olivier (1978), agreeing to the Hoffmann's estimate concluded that the true numbers are nearer 4,000 than 2,000 as estimated by MacKay. Hoffmann (1978), revised his earlier estimate and put forth a figure 5,000. About two decade later, Jackson & Kemf (1996), reported population size between 2,500 and 3000 while Santiapillai *et al.* (1999) concluded that there are about 4,000 elephants.

3.2.13 Andaman Islands

Elephants were brought to the Andaman islands for timber operations and did not traditionally inhabit the place. The present wild population is comprised of feral descendants of escaped timber elephants. The numbers have increased over a period of time and about 20 – 30 elephants are probably surviving on the islands (Sukumar, 1992). Sivaganesan and Kumar (1995), estimated a population of 70 inhabiting

Interview Island Wildlife Sanctuary and eight elephants in two groups in Diglipur Forest Division of North Andaman. Recently a resident of Port- Blaire has informed me that elephant numbers have increased during last 20 years, which is evident from the sharp increase in human-elephant conflict incidences.

3.2.14 Indonesia (Sumatra)

Elephants are distributed throughout Sumatra except the province of Sumatra Utara (Fig. 3.14). The stronghold of elephants however, is in the provinces of Aceh, Riau and Lampung. Sukumar (1992) commented that most other scattered populations are small and hence seems nonviable. He further stated that the creation of large protected areas may offer some prospects for future survival of elephants in Sumatra.

As far as enumeration of elephant numbers is concerned, there are differences among the various estimates put forth by different workers. Olivier (1978) estimated a population of 300 elephants only, while Sukumar (1992) gave a figure between 2,800 and 4,800 based on the surveys carried out by the WWF between 1984 and 1987. More or less similar estimates were given by Jackson and Kemf (1996). They reported a population size between 2,500 and 4,500. Undoubtedly, Olivier had grossly underestimated the population size of elephants in Sumatra.

3.2.15 Borneo (Malaysia/Indonesia)

There are two distinct populations; one is in northern Borneo in the Malaysian province of Sabah and another is in the adjoining area of east Kalimantan, Indonesia (Fig. 3.14)). The estimated population ranges between 500 and 2000 as reported by Sukumar (1992). The origin of elephants in Borneo is questionable and it is believed that elephant population is not indigenous but the surviving elephants

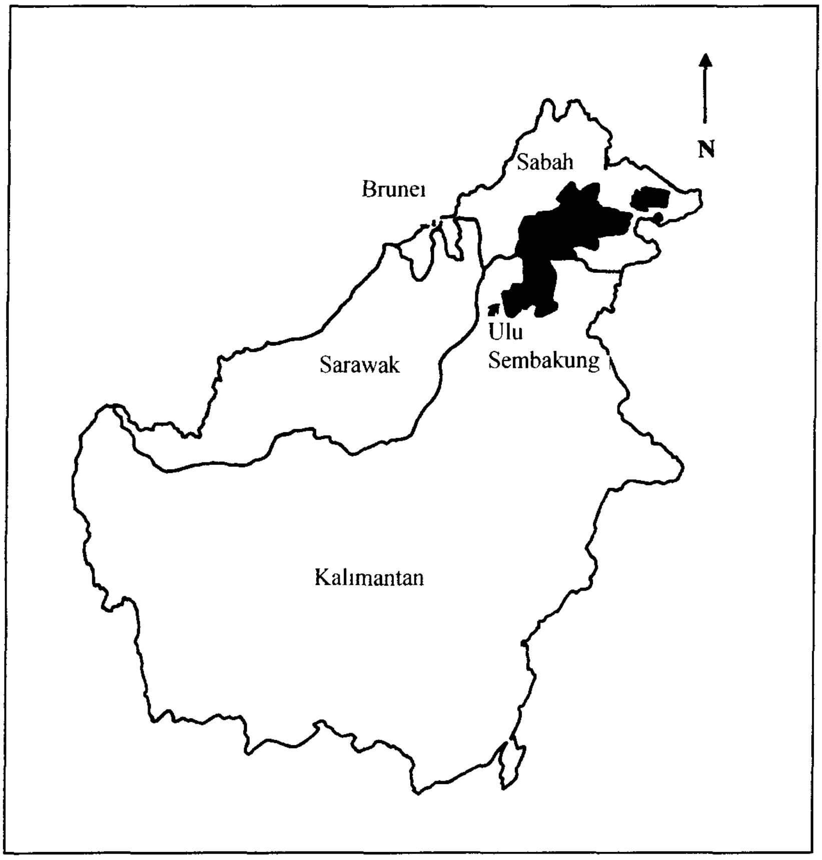


Fig. 3.14 Distribution of Asian Elephants in Borneo (Kalimantan & Sabah).

are descendant of captive ones presented to Sultan of Sulu in 1750 by the East India Company which were then set free in northern Borneo (Olivier, 1978).

3.3 Summary and Conclusions

A summary of the elephant population estimates for range countries is presented in Table 3.1. There are considerable discrepancies as far as number of elephants in the wild are concerned, mainly due to the lack of proper surveys and inadequate information from several range countries. Most of the information on population size before 1980's, barring a few, is based on educated guesses and hence does not allow to draw any meaningful conclusion on the population trend. However, an analysis of available accounts on the population size of last three decades reveals that in most of the range countries of continental southeast Asia, elephant populations have reduced mainly due to the loss of habitat and fragmentation. Elephant populations in the Indian sub-continent seems to be increasing however in my opinion this may not be a virtual increase in population but more so due to their compression within the protected areas and systematic and consistent efforts in estimating numbers. Population of elephants in Andaman Islands has certainly increased, while no conclusion on the population trend of island Asia (Sri Lanka, Sumatra and Borneo) can be drawn as the existing information is either insufficient or highly discrepant. This certainly calls for consideration of a policy to initiate planned studies to find out the current population status, trends and also monitor population size in various range countries. Concerted efforts for such study are urgently required.

Table 3.1 Summary of estimated population size of the Asian Elephants in range countries. Min.= minimum, Max.= maximum.

Region/countries	Olivier 1978		Sukumar 1992		AESG 1996	
	Min.	Max.	Min.	Max.	Min.	Max.
Indian sub-continent						
Northwestern India	550	550	750	750		
Northeastern India	4500	4500	8525	11930		
Central India	900	2000	1635	2335	20310	24485
Southern India	4000	8000	6950	8850		
Bhutan	*	*	60	60	60	150
Nepal	*	*	50	85	50	85
Bangladesh	*	*	200	350	200	250
Sub total	**9950**	**15,050**	**18,160**	**24,360**	**20,620**	**24,970**
Continental Southeast Asia						
Myanmar	5000	5000	6000	10,000	5000	6000
China	100	100	100	230	250	350
Thailand	2500	4500	2925	4550	1500	3000
Laos, Cambodia , Vietnam	3500	4500	4500	7000	4250	6400
Peninsular Malaysia	3000	6000	800	3000	800	1000
Sub total	**14,100**	**20,100**	**14,325**	**24,780**	**11,800**	**16,750**
Island Asia						
Sri Lanka	2000	4000	2000	4000	2500	3000
Andaman Islands	30	30	20	30		
Sumatra	300	300	2800	4800	2500	3600
Borneo	2000	2000	500	2000	750	1000
Sub total	**4330**	**6330**	**5320**	**10,830**	**5750**	**7600**
Grand Total	**28,380**	**41,480**	**37,805**	**59,970**	**38,170**	**49,320**

*Separate figures are not given for elephant population of Bhutan, Nepal and Bangladesh but included in Northwest and Northeast Indian populations thus representing the total population for the Indian sub-continent.

Chapter 4: Habitat structure and composition

4.1 Introduction

The structure and composition of vegetation play an important role in influencing various aspects of ecology of animal populations and especially of elephants, as they are directly dependent on it. It is well documented that apart from physical and environmental characteristics of habitats, the vegetation largely governs the movement and ranging, feeding and habitat utilization patterns of elephant populations in time and space e.g. Laws *et al.* (1970), Olivier (1978), Short (1983), Merz (1986) and Sukumar (1989). Both, the Asian and the African elephants have been seen influencing and modifying vegetation in areas they inhabit mainly due to their feeding behaviour e.g. Wing and Buss (1970), Vancuylenberg (1977), Ishwaran (1983), Okula and Sise (1986), Mwalyosi (1987 & 1990) and Jachmann and Croes (1991). This has prompted researchers to monitor various parameters of habitat in order to detect changes and to assess the impact on animal populations as well as by the animal populations on their habitat. The results of such long-term monitoring of habitat enable researchers to establish definite relationships between animal population and habitat parameters, which can be used to design effective management strategies. In fact, the importance of habitat monitoring was realized much earlier and in several of the East African wildlife reserves, habitat oriented management strategies were implemented which have shown encouraging results. The classical example is of Serengati ecosystem. However, in India, the wildlife management has so far been largely species oriented ignoring the proper scientific monitoring of vegetation as well as other habitat parameters, which sometime has resulted in failure due to the fact that changes in habitat characters significantly affects the fauna (Khan, 1993).

The elephant population in north west Uttar Pradesh in general and in Rajaji National Park in particular is steadily increasing as evident from the status surveys carried out between 1969 and 1995 (Singh, 1969; 1978 & 1986; Singh, 1995). At the same time, a qualitative change in habitat structure and composition is noticeable in the form of habitat fragmentation, degradation and shrinkage, mainly due to increasing human and livestock pressures on the Rajaji ecosystem. Elephant populations under such constraints are compressed in limited areas and may bring changes in habitat composition and structure, which in itself may be detrimental for log-term survival of elephant population. In view of this a systematic study on vegetation and other habitat components of Rajaji was initiated to collect baseline information with the aim that the results of present study would be helpful in understanding elephant –habitat relationship. It may further be utilized in future for comparison purposes in order to detect likely changes in habitat and its impact on the elephant population.

This chapter contains quantitative information on various aspects of vegetation of Rajaji such as species composition, diversity, richness and dominance, assessment of population structure and status of weeds. It also provides information on the regeneration status of selected tree species and assessment of human and livestock impact on the vegetation.

4.2 Methodology

Studies on vegetation composition and community structure were carried out in the intensive study area –the former Rajaji Sanctuary hereafter referred as Rajaji. The vegetation of Rajaji is more or less homogenous with *Shorea robusta* (Sal) being the numerically abundant tree species. However, based on the tree species composition, forest structure and occurrence of species on hills and plains the vegetation of Rajaji was subjectively classified in to six different types, which are as follows.

i) Mixed forest on plains

ii) Sal forest on plains

iii) Plantations

iv) Sal mixed forest on hills

v) Sal forest on hills

vi) Mixed forest on hills

4.2.1. Field data collection

Vegetation sampling was carried out by establishing 17 line transects of varied lengths totaling 130.5 km spread over proportionately in all the subjectively classified vegetation types. Data on species composition was collected using point centred quarter (PCQ) method as described by Muller-Dombois and Ellenberg (1974). Sampling points were established at a fixed interval of 100 m on the line transect. Distances to four nearest trees and shrubs were measured separately in each quarter and plant species were identified on every sampling point. Following variables were also recorded at each sampling point:

1) Terrain type - flat, undulating, lower slope, upper slope, valley

2) Vegetation type

3) GBH of each tree sampled
4) Lopping status (lopped / not lopped)
5) Height of each tree by ocular estimation

Plants with 30 cm or more girth at breast height (GBH at a height of 1.5m from the ground) were considered as trees while the plants smaller than 30 cm GBH were categorized as shrubs. Plants not bearing GBH but measuring 50 cm to 3 m in height above ground were also considered as shrubs. Plant species such as *Lantana camara, Adhatoda zeylanica, Helicteres isora, Ziziphus oenoplia* and *Dendrocalamus strictus* with more than 50 cm of height and irrespective of maximum height were considered as shrubs. Multi-stemmed plant irrespective of stem numbers but with complete canopy was considered as a single individual.

The terrain types were recorded mainly due to the fact, that structurally the vegetation on hills differs with that of the plains as far as tree growth and densities are concerned. About one third of Rajaji Sanctuary is on almost flat land, very gently slopping towards its southern boundary while it rises in the north into a series of dissected Shivalik hills. There are few patches where ground raises between 20 to 50 m in relation to flat ground and then merges into slopes of the hills, such patches have good loam with relatively thick soil layer and hence are categorized as 'undulating'. From the base to the middle of a hill, slopes are mostly gentle and are termed as 'lower slopes', while rest of the slopes above it considered as 'upper slopes'. There are narrow gullies between hills through those seasonal streams flow. Such areas are mostly eroded due to high water runoff during monsoon and are loaded with debris of the hills and hence have poor soil layer. These areas are classified as valleys. Figure 4.1 shows the diagrammatic representation of terrain types.

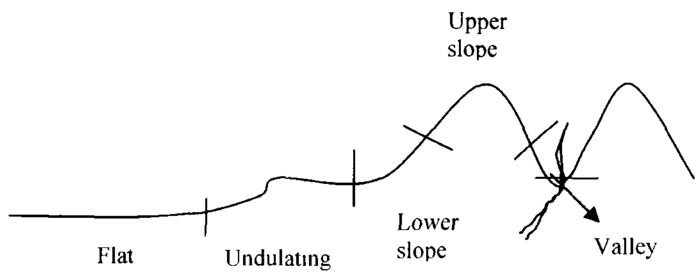


Fig. 4.1 Diagrammatic representation showing classification of terrain types.

4.2.2 Data analysis

Density of trees and shrubs were calculated in different vegetation types, terrain types and administrative units (forest blocks) following Muller-Dombois and Ellenberg (1974). However, for the purpose of comparison of densities among different vegetation types, terrain types and among forest blocks, tree and shrub densities were calculated at each sampling point separately and added together to obtain mean densities for different strata. These density values were statistically compared to understand the differences between different strata, terrain and administrative units using one way ANOVA. Since the density values did not present normal distribution, therefore they were log transformed which has brought near normalcy in the distribution and hence satisfied the requirement of using one way ANOVA. The same procedure was adopted to see the differences in mean GBH and mean height of trees across various vegetation and terrain strata as well as among different forest blocks.

Tree and shrub diversity values were calculated using Shannon- Wiener diversity index as described by Krebs (1989) i.e. $H = -\sum pi x \log pi$, where pi = proportion of i^{th} species in a sample. Species richness was calculated using Margalef's species richness index (Krebs 1989) i.e. R = S-1 / ln N, where S = Number of species and

N = Number of individuals. Evenness was calculated through the formula based on the Shannon-Weiner function as given by Krebs (1989), i.e. $J = H / H_{max,}$ where H = Shannon-Weiner function and $H_{max} =$ maximum value of H or log S (S = number of species).

To assess the overall similarity among different vegetation types in terms of species richness, Sorenson's similarity index (SI) was calculated. SI = 2C/ (A+B) where C = number of common species in area A and B, A = total number of species in area A and B = total number of species in area B.

To compare the structure and dominance of various species among different vegetation types, Importance Value Index (IVI = Relative density + Relative frequency + Relative dominance) was computed for tree species in different vegetation types following Muller-Dombois and Ellenberg (1974).

The relationship between tree densities and other habitat parameters was quantified by performing correlation using the Spearman rank correlation coefficient. All statistical tests were performed using computer programme SPSS for Windows (version 10.0)

Data on tree lopping were summarized as percentage of trees lopped in each forest block and also of a species. To detect the significant differences in lopping among various forest blocks as well as tree species, the Bonferroni confidence intervals were constructed following Byers *et al.* (1984). Percentage of weed shrubs were calculated in various forest blocks and Bonferroni confidence interval were constructed to see the significant differences in occurrence of weeds among various forest blocks.

4.3 Results

The following results are based on the data collected along 17 transects of total length of 130.5 km. The vegetation and other habitat parameters were recorded on 1305 sampling points along these transects.

4.3.1 Tree species richness, diversity and evenness

A total of 71 tree species were recorded on sampling points in Rajaji across various vegetation types. Maximum numbers of species (65) were recorded in mixed forest on hills. It was followed by plantations (51) and Sal mixed forest on hills (42) while minimum numbers of species (22) were recorded in Sal forest on hills. A comparison of tree species richness, diversity and evenness among different vegetation types showed that species richness (Margalef's RI) and diversity (Shannon's *H*) were highest in mixed forest on hills (8.31 and 1.37 respectively) and it was lowest in Sal forest on hills (3.66 and 0.76 respectively). The maximum evenness was observed in mixed forest on plains and minimum in Sal forest on plains, however the differences were marginal ranging between 0.52 and 0.86. The values of species richness, diversity and evenness among different vegetation types are given in Table 4.1.

Species richness, diversity and evenness was observed maximum on undulating terrain however no clear cut pattern emerged in richness, diversity and evenness among other categories of terrain. Species richness varied significantly between different categories of terrain and it ranged from a minimum of 4.77 in the valleys to a maximum of 8.45 on the undulating terrain. Marginal differences, in diversity (1.17 to 1.5) and evenness (0.68 to 0.89) values were observed among various terrain types (Table 4.2).

The species richness, diversity and evenness values among various administrative units (forest blocks) of Rajaji are given in Table 4.3. The maximum richness (7.53) was observed in Betban forest block while both; the diversity and richness were observed highest (1.37 and 7.16 respectively) in Sukh forest block. The evenness values differed marginally among different forest blocks ranging between a minimum of 0.66 in Tira and a maximum of 0.85 in Mohund forest blocks.

4.3.2 Relationship between species richness, diversity and evenness

Tree species richness increased with increasing diversity as indicated by a significant positive correlation between the two ($r_s = 0.793$, $N = 17$, $P < 0.01$). There was also a positive correlation between species diversity and evenness values ($r_s = 0.676$, $N = 17$, $P < 0.01$). The values of species richness and evenness however were not correlated ($r_s = 0.186$, $N = 17$, $P > 0.05$).

4.3.3 Tree species richness, diversity and abundance of weeds

Growth of weed shrubs had an adverse impact on the tree species richness, as it was discernible from negative correlation between the richness and weed density values ($r_s = -0.549$, $N = 17$, $P < 0.05$). The values of tree species diversity however were not correlated with that of the weed densities ($r_s = -0.153$, $N = 17$, $P > 0.05$).

4.3.4 Tree densities in various strata of Rajaji

The mean density (trees/ha) of tree species varied significantly among different vegetation types ($F_{5\ \&\ 1299} = 31.8$, $P < 0.01$), terrain types ($F_{4\ \&\ 1300} = 36.9$, $P < 0.01$) and among various forest blocks ($F_{16\ \&1288} = 15.3$, $P < 0.01$) in Rajaji. Tree density among various vegetation types ranged between 377 and 592. Significantly high tree density (592 trees/ha) was recorded in plantations. This was followed by mixed forest on plains (574 trees/ha), Sal forest on plains (544 trees/ha) and Sal forest on hills (510 trees/ha). The lowest density (377 trees/ha) was recorded in mixed forest on hills (Table 4.4). Similarly, significant differences in tree densities were recorded among various categories of terrain. The highest tree density (581 trees/ha) was recorded on the flat terrain while lowest (365 trees/ha) in the valleys (Table 4.5). Significantly high tree densities were recorded in forest blocks such as Tira (942 trees /ha), Sendhli (878 trees/ha) and Ganjarban (605 trees/ha) as compared to other forest blocks (Table 4.6).

4.3.5 Mean tree girth in various strata of Rajaji

The mean GBH values of trees among different vegetation types differed significantly ($F_{5 \& 1299} = 21.2$, $P < 0.01$). It was high in Sal forest on plains (90.4 ± 4.7 cm.) and Sal mixed forest on hills (89.9 ± 2.9) as compared to other vegetation types (Table 4.4). Among the various terrain categories, the maximum GBH value (104.7 ±9 cm) was recorded on undulating terrain while the minimum (77.1 ± 2.2 cm) was on flat terrain (Table 4.5) and the differences were significant ($F_{4 \& 1300} = 22.6$, $P< 0.01$). Similarly, there was a significance difference in GBH values of trees among various forest blocks ($F_{16 \& 1288} = 13.3$, $P< 0.01$). Significantly high GBH values were recorded in forest blocks such as Mohund (92.3 ± 7.4 cm), Baniawala (91.9 ± 4.1), Betban (90.7 ± 5.2) and Chillawala (Table 4.6).

4.3.6 Mean tree height in various strata of Rajaji

The mean tree height was more in Sal and Sal mixed forests as compared to the mixed forests and plantations and the values ranged between 6.96 ± 0.97 m and 9.76 ± 0.42 m (Table 4.4). The analysis of data suggested that there was a significant difference in mean tree height among various vegetation types ($F_{5 \& 1299} = 16.3$, $P< 0.01$). There was also a significant difference in tree height among various terrain types ($F_{4 \& 1300} = 28.1$, $P< 0.01$). The maximum tree height was recorded on undulating terrain (10.51 ± 0.64m) and minimum on flat terrain (8.5 ± 0.23 m). The values of mean tree height among various categories of terrain are given in Table 4.5. Similarly, significant differences in mean tree height were observed among various forest blocks of Rajaji ($F_{16 \& 1288} = 11.6$, $P < 0.01$). Maximum tree height (10.49 ± 0.94 m) was recoded in Mohund forest block while minimum (6.77 ± 0.67 m) in Ganjarban forest block (Table 4.6).

4.3.7 Relationship between tree density, girth and height

The analysis of data suggested that the there was an inverse relationship between tree density and girth i.e. the forest blocks with more tree densities had low mean tree girth ($r_s = -0.487$ N = 17, $P < 0.05$). Similarly the mean tree height among different forest blocks was found negatively correlated with tree densities ($r_s = -0.530$, N = 17, $P < 0.05$).

4.3.8 Tree species similarity among vegetation types

The analysis of the data on species composition among various vegetation types suggested that several of the tree species were common in all the vegetation types. The values of Sorenson's similarity index indicated that barring a few cases, any two vegetation types had about 50% similarity as far as species composition is concerned. Sal forest on hills was least similar with that of the mixed forest on hills. The similarity was also found least between mixed forest on plains and Sal forest on hills, while more than 75% similarity existed between Sal mixed forest on hills and mixed forest on hills. The values of Sorenson's similarity index are given in Table 4.7.

4.3.9 Tree species composition and dominance among vegetation types

Tree species composition and dominance differed significantly among different vegetation types. *Shorea robusta* (Sal) was found as a dominant tree species, occurring in all the vegetation types with varying density and IVI values. The highest IVI of *S. robusta* (175) was recorded in Sal forest on plains and lowest in plantations. *Mallotus philippensis* was dominant species in mixed forest on plains, while it occurred in all the vegetation types as an under canopy tree. Other tree species common to all six vegetation types were *Acacia catechu, Bauhinia purpurea, Ehretia laevis* and *Kydia calycina.*

4.3.9.1 Tree species composition and dominance in mixed forest on plains

A total of 31 tree species were recorded in mixed forest on hills, however about 60 % of this vegetation type was composed of only six species. *Mallotus Philippensis* had the highest density (114 trees/ha) as well as IVI (45). However, the top canopy was composed of *Lagerstroemia parviflora* and *Shorea robusta* but in low densities (8.33 and 4.17 trees/ha respectively). The other co-dominant understory tree species were *Ehretia laevis, Acacia catechu, Kydia calycina* and *Miliusa velutina.* The information on the density, percentage and IVI of different tree species is provided in Table 4.8.

4.3.9.2 Tree species composition and dominance in Sal forest on plains

In this vegetation type, the density (301trees/ha) and the IVI (175) of *S. robusta* was found highest contributing about 55% of the total stand density. Other species occurring with Sal and contributed more than 5% of the total stand density were *Ehretia laevis* (47 trees/ha), *M. philippensis* (51trees/ha), *L. parviflora* (48 trees/ha) and *M. velutina* (22 trees/ha). The rest 25 species occurring in this vegetation type had less than 1% contribution in total density barring *Ziziphus xylopyra* and *A. catechu* (Table 4.9).

4.3.9.3 Tree species composition and dominance in Plantations

A total of 51 tree species were recorded in plantations. The upper canopy was dominated by *Acacia catechu* and *Dalbergia sissoo* with more or less equal IVI values of 36.8 and 34.2 and density values of 98 and 88 trees/ha respectively. This was followed by species such as *Ailanthus excelsa* and *Tectona grandis*. Other tree species growing in this vegetation type had fractional contribution in densities and IVI values (Table 4.10). Except a few small patches of monoculture (*Ailanthus and Tectona*), the plantations in Rajaji were carried out as part of gap filling exercise after selective felling of trees under the silvicultural operation until early 1980s, thus representing elements of all other vegetation types. This vegetation type was described separately in order to see the changes in vegetation composition as a result of past management practice.

4.3.9.4 Tree species composition and dominance in Sal mixed forest on hills

Sal occurred in mixed form on hills with 41 other species as well as in pure patches with fewer species as its associates and hence was classified in to two different vegetation types; Sal mixed forest on hills and Sal forest on hills. *S. robusta* was the dominant species in both the vegetation types but with varying density and IVI values. In Sal mixed forest the density of *S. robusta* was recorded 142 trees/ha with an IVI of 109. Other co-dominants were *Anogeissus latifolia, Terminalia alata* and *Ougeinia oogeinsis*. On higher elevations where soil was comparatively dry, Sal occurred with *Pinus roxburghii* and *Buchanania lanzan*. Other species growing along with Sal on hills were *Acacia catechu, Bauhinia purpurea, Ziziphus xylopyra, M. philippensis, L. parviflora, E. laevis, Kydia calycina, Terminalia bellirica, Lannea coromandelica, Emblica officinalis, Litsea glutinosa* and others (Table 4.11).

4.3.9.5 Tree species composition and dominance in Sal forest on hills

In Sal forest on hills, *S. robusta* contributed more than 56% in total density of this vegetation stratum with a highest IVI value of 161. Other top canopy tree species occurring with Sal were *A. latifolia, B. lanzan*, and *T. alata* but in low densities and with low IVI values. The understory was mainly constituted by species such as *Ougeinia oogeinsis, M. philippensis, E. laevis, Bauhinia purpurea, Kydia calycina* and *A. catechu* (Table 4.12).

4.3.9.6 Tree species composition and dominance in Mixed forest on hills

A. latifolia in mixed forest on hills had contributed about 17 percent in the total tree density and also had highest IVI value (53). *Shorea robusta* occurred in low densities (36 trees/ha) and had a lower IVI (30) value. A total of 65 tree species were recorded in this vegetation type but only seven species had tree densities more than 5% while rest of the species occurred in low densities contributing less than one percent. Table 4.13 provides density, percentage and IVI values for different tree species in mixed forest on hills.

4.3.10 Status of tree lopping

Lopping by the local tribe (the Gujjar) was considered as one of the conservation problems to the well being of the Rajaji ecosystem. The analysis of the data revealed that lopping was significantly higher than the proportional availability of trees in the four forest blocks while it was proportional to the available trees in another four forest blocks and was found significantly low in eight forest blocks. Lopping was not recorded in Dholkhund block as the forest department had been enforcing a complete ban on lopping and grazing in this block. The maximum percentage of lopping (55%) was recorded in Gholna forest block and it was followed by Bam and Betban (48% in each forest block) and Chillawala (46%) forest blocks. In rest of the forest blocks the instances of lopping ranged between less than one and 37 percent (Table 4.14).

A total of 52 tree species were found lopped in Rajaji. The simultaneous Bonferroni confidence intervals were constructed for only 23 species. These species had five or more individuals lopped. The analysis of the data showed that the maximum lopping was recorded for *Grewia elastica* (86%) followed by *Anogeissus latifolia* (71%). The other tree species lopped in significantly higher proportion than their availability were *Terminalia alata* (69%), *Bauhinia purpurea* (56%) and *Ougeinia oogeinsis* (54%). Species such *Acacia catechu, Shorea robusta*, and *Ziziphus xylopyra* were lopped in significantly lower proportions than their availability. The remaining 15 species were found lopped in equal proportions to their availability (Table 4.15).

4.3.11 Relationship between tree species richness, diversity, density and lopping

It was observed that the tree lopping was maximum in forest blocks where tree species diversity and richness were high. The values of both, the species diversity and the richness were positively correlated with the number of looped trees (r_s = 0.526, N = 17, P< 0.05 and r_s = 0.640, N = 17, P< 0.01). However, there was no significant correlation between the values of tree densities and the number of tree lopped (r_s = - 0.208, N=17, P>0.05).

4.3.12 Tree population structure in different forest blocks

The general forest structure in various forest blocks based on estimates of girth class frequencies of all trees, showed that the populations of tree stands in at least six forest blocks were of expanding type. These forest blocks were Ganjarban (Fig. 4.2 A), Lakkarkot (Fig.4.2 B), Dholkhund (Fig. 4.2 H), Malowala (Fig.4.2 I), Tira (Fig. 4.2 P), and Sendhli (Fig. 4.2 Q). However, the forest stand in Ganjarban, Tira and Sendhli blocks were comparatively young as indicated by low representation in higher girth classes. The stand level population structure in remaining forest blocks indicated low recruitment as low frequencies in 30-60cm girth class were recorded barring Rasulpur forest block (Fig. 4.2).

4.3.13 Population structure of dominant tree species

Ten numerically abundant species recorded during the sampling were selected to understand the trends in population structure. It was found that four native (*S. robusta, A. latifolia, T. alata, D. sissoo*) and one planted exotic tree species (*Ailanthus excelsa*) had considerably low frequencies in 30-60 cm girth class (Fig. 4.3 a, b, e, f, & j) indicating poor regeneration and recruitment in the recent past. *Pinus roxburghii* had considerably low frequencies in 30-60 and 61-90 cm girth classes (Fig 4.3 h). Species such as *A. catechu, O. oogeinsis, M. philippensis* and *E. laevis* had expanding population structure (Fig. 4.3 c, d, g, & i), however occupying less of space with low representation in almost all girth classes except one (30-60 cm girth class) compared to dominant *S. robusta* and *A. latifolia* (Fig. 4.3 a & b). Considering the present trend as depicted in Fig. 4.3 h, it can be prefigure that the population of *P. roxburghii* is heading towards extermination while the dominant species such as *S. robusta, A. latifolia T. alata and D. sissoo* would eventually be replaced in future by their associate species.

4.3.14 Density, richness, diversity and evenness of shrubs in various strata of Rajaji

The shrub density differed significantly among different vegetation types ($F_{5 \& 1078}$ = 28.1, P< 0.01), terrain type ($F_{4\&1079}$ = 47.3, P< 0.01) and among various forest blocks ($F_{16 \& 1067}$ = 10.7, P< 0.01). The density of shrubs was found highest in Sal forest on plains (3790 plants/ha) and it was followed by mixed forest on plains (3633 plants/ha) and plantations (3116 plants/ha). The lowest shrub density was recorded in mixed forest on hills (Table 4.16). Among various terrain types, higher shrub densities were recorded on the undulating and the flat terrain as compared to the slopes and the valleys. It was highest (3243 shrubs/ha) on the flat terrain and lowest (1370 shrubs/ha) in the valleys (Table 4.17).The shrub densities ranged between 1557 shrubs/ha and 5712 shrubs/ha among different forest blocks and it was recorded highest in Baniawala and lowest in Gholna forest blocks (Table 4.18).

The shrub richness was significantly high in Sal forest on hills and it was nearly doubled as compared to the richness recorded in mixed forest on hills. Among rest of the vegetation types i.e. mixed forest on plains, Sal forest on plain and plantations the shrub richness differed marginally between them (Table 4.16). Significant differences were also recorded in shrub richness among various terrain types. Considerably higher richness values were recorded on the upper and the lower slopes as compared to the valleys, flat and the undulating terrains. Shrub richness was maximum on the lower slopes while it was minimum on the undulating terrain (Table 4.17).

Species diversity of shrubs differed between various vegetation and terrain types however, the differences were marginal. Comparatively high diversity values were recorded in mixed vegetation types than in Sal forests and plantations and it ranged between 0.75 and 1.19. The maximum diversity value was recorded in mixed forest on hills and minimum in plantations (Table 4.16). Marginal variations in shrub diversity values were observed between the lower slopes and the valleys and between flat and the undulating terrains. The shrub diversity value was maximum (1.22) on the upper slopes and it was minimum (0.80) on the undulating terrain (Table 4.17).

The maximum value of evenness was recorded in mixed forest on plains (0.83) and minimum in plantations (0.55). The evenness values were more or less similar between Sal mixed forest on hills and Sal forest on hills (Table 4.16). Among different terrain types, the evenness values ranged between 0.63 and 0.85. The maximum evenness was observed in valleys and the minimum on undulating terrain (Table 4.17).

4.3.15 Composition of shrubs in different vegetation types

A total of 46 shrub species in Rajaji were recorded. The occurrence of species number as well as the densities significantly differed across various vegetation types. *Mallotus philippensis* was found dominating the shrub layer at least in four, out of six vegetation types. It constituted about 19 percent of the total density of shrubs in mixed forest on plains, about 48 percent in Sal forest on plains and plantations while *Mallotus* constituted 20 percent of the total shrub density in Sal mixed forest on hills. Other species at shrub level common to all vegetation types were *Lantana camara, Adhatoda zeylanica Helicteres isora, Ehretia laevis* and *Cassia fistula.* The maximum density of *L. camara* (1510 clumps/ha) was recorded in plantations while comparatively lower densities were recorded in other vegetation types ranging between 69 and 681 clumps /ha. The density of *A. zeylanica* was recorded highest in plantations (574 clumps/ha) and lowest (155 clumps/ha) in Sal forest on hills. Highest density of *Helicteres isora* (454 plants/ha)) was recorded in mixed forest and it ranged between 31 and 294 plants /ha in other vegetation types. *Ehretia laevis* and *Cassia fistula* though occurred in all vegetation types but in much lower densities. The complete lists of species along with their densities among different vegetation types are given in Tables 4.19 to 4.24.

4.3.16 Status of weeds at shrub layer across different forest blocks

Lantana camara and *Adhatoda zeylanica* were the common weeds at shrub layer present in all forest blocks though in varying densities. Significantly higher densities of weeds were recorded in Baniawala (5304 clumps/ha) and Lalwala (3497 clumps/ha) forest blocks as compared to other forest blocks of Rajaji. The weed density in rest of the forest blocks ranged between 21 and 1367 clumps/ha. In Baniawala and Lalwala forest blocks, weeds constituted 92 and 88 percent respectively of the total shrub densities recorded in these blocks (Table 4.18). The results of the simultaneous Bonferroni's confidence interval constructed on the proportion of weed and non-weed shrubs suggested that the occurrence of weeds was significantly higher than the occurrence of non-weed shrubs in three forest blocks i.e. Baniawala, Lalwala and Tira. The occurrence of weed shrubs was found proportional to the occurrence of non-weed shrubs in seven forest blocks while it was significantly lower in rest of the forest blocks.

4.4 Discussion

The vegetation of Rajaji is mainly composed of heterogeneous deciduous species of tropical and sub-tropical origin and tree species are not very distinctly arranged in space to form definite vegetation classes. However, some poorly distinct classes can be recognized based on the relative dominance of *Shorea robusta* at top canopy level. Small pure patches of *Shorea* occur on flat terrain as well as on hill slopes with few other under canopy species as its associates and hence classified in to two different vegetation types; the Sal forest on plains and the Sal forest on hills. A larger part of Rajaji is being occupied by mixed vegetation with Sal occurring all over in varying densities. The areas where the top canopy is dominated by Sal but also shared by other species were classified as Sal mixed forest and where the top canopy was dominated by other than Sal, were classified as mixed forest. There are small pure patches of *Ailanthus excelsa, Acacia catechu* and *Dalbergia sissoo* those were planted after clear felling during the time when forestry operations were carried out and crop harvesting was a practice. Most of such patches were more than 20 years old and now appear as a part of natural vegetation except small patches of *Ailanthus excelsa.* Apart from them, the forest department also carried out plantations in areas where selective felling was done in the past to fill the gaps and to increase forest density. All such areas were classified as plantations mainly to detect changes in the species composition and forest structure as a result of past management practices.

The subjective classification of vegetation types based on the ground surveys seems to be satisfactory in order to discriminate between different patches within the mosaic of heterogeneous vegetation, which may offer differential availability of food and cover to animal species, particularly the elephants. From the point of view of vegetation ecology, this subjective classification may not be the best method, however the aim of this study was not to work out vegetation ecology alone per se but to provide a classification, which may be helpful in explaining habitat use, movement, ranging and feeding patterns of elephants among different patches in Rajaji.

In general, the values of diversity index are higher in tropical forests as compared to the temperate. Knight (1975) reported the diversity index as 5.06 for young and 5.04 for old tropical forest on Barro Colorado Island, Panama. However, for tropical forests of India the diversity index values ranged between 0.83-4.1 as reported by Singh *et al.* (1984), Parthasarthy *et al.* (1992) and by Visalakshi (1995). The values of diversity index (1.25-1.50) obtained during the present study are well within the reported range.

The low species richness and diversity in Sal dominated vegetation types can be attributed to the fact that Sal in this zone is regarded as climax species (Champion &

Seth, 1968; Singh & Singh, 1987) and hence it occupy most of the ecological space, leaving little for other species to establish. Rawat and Bhainsora (1999) have recorded low species diversity and richness in high density Sal forest in Doon valley as compared to the low density Sal forest in Shivalik. Pande (1999), in Sal forests around Rajaji National Park also reported similar pattern in species richness and diversity. This implies that as the proportion of Sal increases the species richness and diversity decreases in Sal dominated forests in and around Shivalik zone. The differences in species richness and diversity among various terrain types can be attributed to the moisture gradient and soil conditions. The higher values of species richness and diversity on undulating terrain were related to better soil condition and moisture as compared to lower and upper slopes. In the valleys, one would expect much better soil conditions and moisture, however, in Shivaliks, valleys or ravines have sandy soil mixed with lose agglomerate of the hills and low moisture due to high porosity. Such areas support grasses and shrubs with few tree species and therefore have low tree species diversity and richness as compared to other terrain types. Rawat and Bhainsra (1999) also recoded lowest values of tree species diversity in the valleys of Shivaliks.

The lower values of richness and diversity in forest blocks such as Ganjarban, Lakkarkot, Rasulpur, Lalwala, Baniawala and Tira as compared to the rest of the forest blocks were due to high human pressure on the forest for want of various forest produce including timber. In the past, until 1980 selective felling of trees were also carried out in these forest blocks as a part of forestry operations before the declaration of this area as Rajaji National Park and this alone a reason enough for low tree species richness and diversity.

The range of tree density (365-592 trees/ha) as recorded among different vegetation and terrain types in the present study was well within the range (438-499 trees/ha) as reported by Sundarraj *et al.* (1995) from the adjacent areas of Shivalik hills. The tree density were also comparable with other tropical areas such as those in Costa Rica, 448-617 (Heaney & Proctor, 1990), Malaysia, 250-500 (Primack & Hall, 1992) and in Brazil, 420-777 (Campbell *et al.*, 1992).

At stand level, mean tree density values were negatively correlated with both; the mean tree GBH and height values. This indicates that more number of trees with low individual volume and biomass are utilizing the ecological space. Significantly, high densities in Tira and Ganjarban forest blocks were due to low GBH. In general, the tree density of individual species is affected by the micro climatic and environmental conditions, production of seeds, effectiveness of seed dispersal and germination, survival of seedlings and also by the edaphic factors such as fire, extraction of plant resources either removal of seeds, plants or heavy grazing etc. Apart from other factors, tree densities among various vegetation types were probably more influenced by the topographical variations in Rajaji.

The IVI values of different tree species differed significantly within as well as between vegetation types. The highest IVI values were of Sal at least in three vegetation types, which ranged between 109 and 175. These values were well within the range (106-179) reported by Pande (1999) from the adjacent Sal forests in Shivalik while Rawat and Bhainsora (1999), reported higher IVI for Sal (183). The IVI values of different species can best be interpreted through the dominance-diversity curve, which ascertain the resource apportionment among the various species in different vegetation types (Dani *et al.,* 1991). The D-D curves (Fig. 4.4) for various vegetation types show log normal distribution of Preston (1948) implying that fewer species with high IVI values occupy top niche. The top niches in mixed forest on plains and mixed forest on hills were occupied by *Mallotus philippensis* and *Anogeissus latifolia* while in rest of the vegetation types it was occupied by *Shorea robusta.* In all the vegetation types, fewer species were observed occupying intermediate niches while rest of the species shared lower niches more or less equally. May (1975), suggested that log normal distribution pattern may be a characteristic of a community with heterogeneous assemblage of species, which is confirmed during the present study.

The similarity in species composition between various habitat types ranged between 45% and 72%. Sal forest on hills was least similar with rest of the vegetation types, however, the similarity values ranged between 45% and 53%. This again confirms the heterogeneous nature of vegetation in Rajaji. The similarity values obtained during the present study are comparable with other studies carried out in the same zone e.g. Rawat and Bhainsora (1999) and Pande (1999).

The perusal of the data pertaining to lopping suggested that occurrence of lopping was significantly higher than the total availability of trees in four forest blocks namely Bam, Chillawala, Betban and Gholna and the percentage of lopping in these forest blocks ranged between 46 and 55. It is expected that such a high level of lopping would certainly create an impact on the vegetation. The most obvious impacts of lopping can be in the form of low regeneration and slow growth of lopped trees and both of them are evident in Rajaji. The examination of stand level population structure suggested that forest blocks with significantly higher occurrence of lopping had low frequencies in 30-60 cm GBH class indicative of low regeneration in the recent past. On the other hand , the low representation in higher girth classes is indicative of retardation in tree growth (Table 4.14 & Fig. 4.2).

In all 71 species of trees recorded in Rajaji, 52 species (72%) were being lopped. All the species those were lopped in significantly higher proportions had low occurrence at shrub level representing poor status of regeneration. A positive correlation between species diversity and richness with that of number of trees lopped in simple terms leads to conclude that lopping had contributed in increasing the species richness and diversity. This simple conclusion would be misleading because of the fact that the rich and diverse vegetation patches provide more palatable and variety of fodder and hence preferred for lopping. However, in order to understand the impact of lopping on the structure and composition of Rajaji vegetation, a long-term study is highly desirable.

The examination of population structure of ten numerically abundant species suggest that the populations of *Acacia catechu, Ougeinia oogeinsis, Mallotus philippensis* and *Ehretia laevis* are of expanding type. In spite of heavy lopping of *O. oogeinsis* (53% of all trees) the regeneration seems to be good withstanding the heavy lopping pressure. *M. philippensis* being one of the preferred food plants of elephant in this area (Khan, 1990) is also showing good regeneration and growing well as an understory tree in all most all the vegetation types enduring heavy browsing by the elephants. *A. catechu* and *E. laevis* are also elephants' food plants but seems to be unaffected by the browsing and showing good regeneration and recruitment. Contrary to that, *Shorea robusta, Anogeissus latifolia, Terminalia alata, Dalbergia sissoo* and *Pinus roxburghii* all had low frequencies in 30-60 cm girth class indicating poor regeneration. Heavy lopping on *A. latifolia* and *T. alata* seems to be probable reasons for poor regeneration. In fact, both these species were not recorded at shrub level. The regeneration of *S. robusta* is generally poor throughout the Shivaliks as has been observed by Rawat and Bhainsora (1999). Pande (1999) also observed poor regeneration of *S. robusta* and termed *E. laevis* and *M. philippensis* as fair reproducers. He further stated that the poor regeneration of Sal is due to good performance of other associate species especially *Mallotus*, which has competed out Sal at sapling stage. Very low representation of *P. roxburghii* in smaller girth classes suggested poor regeneration in the past. At shrub level also very low density of *Pinus* was recorded indicating poor performance of the species. This leads to conclusion that the population of *Pinus* would be replaced by other species growing with pine and had better regeneration.

Significantly, higher densities of shrubs were found on flat and undulating terrain as compared to hilly tracts and in Sal dominated forests as compared to other vegetation types. The higher shrub densities in Sal forests were mainly due to the prolific growth of *M. philippensis* at shrub level. Ideally, the species richness and diversity at shrub level among different vegetation types should follow the similar pattern as that of tree species richness and diversity, however it only appeared similar in mixed forest on hills where tree and shrub richness and diversity were highest. In Sal forest on hills as well as on plains the reason for comparatively low shrub richness and diversity can be attributed to the dominance of *M. philippensis*. In plantations, *Lantana camara* and *Adhatoda zeylanica* have out competed other species contributing low richness and diversity at shrub level. Significantly high occurrence of weeds at shrub level in forest blocks such as Baniawala, Lalwala and Tira is indicative of high degree of disturbance. These forest blocks are at the periphery and have high human and grazing pressure.

4.5 Summary and conclusions

The vegetation of Rajaji is homogeneous in nature and species are not distinctly arranged in space to form definite vegetation classes. Sal (*Shorea robusta*) is the dominant species occurring all over the area in differential densities. The topographical variation seems to be influencing the density, growth and spatial distribution of various species. A total 71 tree and 46 shrub species were recorded during the study, however, the numbers could be more as rare or less frequent species are likely to be missed in such a large area during sampling. Sal forests were less diverse as compare to mixed forest. The management interventions by the Forest Department had a positive effect on the vegetation, especially the gap filling exercises by raising plantations within the natural forests, have increased the density and diversity of the forest stands. The standing crop is better stocked on the flat and undulating terrain as compared to the slopes and the valleys. Forest blocks such as Gholna, Bam, Betban, and Chillawala had high lopping pressure, which may create an adverse impact on the forests in the form of low regeneration and retardation of tree growth. If the similar trend continued, it would lead to further degradation of the forest stand. Low regeneration of *Shorea robusta, Anogeissus latifolia, Terminalia alata, Dalbergia sissoo* and *Pinus roxburghii* may cause gradual replacement of these species by those species showing high regeneration such as *Acacia catechu, Ougeinia oogeinsis, Mallotus philippensis and Ehretia laevis.* High densities of *Lantana camara* and *Adhatoda zeylanica*, at several places especially in forest blocks such as Baniawala, Lalwala and Tira had out competed other species contributing low richness and diversity at shrub level.

Table 4.1 Tree species richness, diversity and evenness among different vegetation types in Rajaji Sanctuary.

Vegetation types	n	N	Richness	Diversity	Evenness
Mixed forest on plains	24	31	6.573	1.278	0.857
Sal forest on plains	99	30	4.848	0.779	0.527
Plantations	321	51	6.986	1.192	0.698
Sal mixed forest on hills	236	42	5.985	1.036	0.639
Sal forest on hills	77	22	3.665	0.765	0.571
Mixed forest on hills	548	65	8.318	1.375	0.759

n = Number of sampling points, N = Number of species.

Table 4.2 Tree species richness, diversity and evenness among different terrain types in Rajaji Sanctuary.

Terrain types	n	N	Richness	Diversity	Evenness
Flat	435	56	7.371	1.257	0.719
Undulating	58	47	8.445	1.502	0.898
Upper slopes	447	52	6.809	1.176	0.685
Lower slopes	318	56	7.694	1.262	0.722
Valleys	47	26	4.774	1.173	0.829

n = Number of sampling points, N = Number of species.

Table 4.3 Tree species density, richness, diversity and evenness of trees in different administrative units of Rajaji Sanctuary.

Forest Blocks	n	N	Richness	Diversity	Evenness
Andheri	100	30	4.842	1.031	0.698
Bam	101	38	6.165	1.157	0.732
Baniawala	49	29	5.305	1.178	0.805
Betban	99	46	7.523	1.266	0.761
Chillawala	101	43	6.998	1.256	0.769
Dholkhund	103	35	5.647	1.158	0.75
Gaaj	100	36	5.842	1.169	0.751
Ganjarban	56	25	4.435	1.169	0.836
Gholna	102	36	5.822	1.188	0.763
Lakkarkot	50	25	4.53	0.945	0.676
Lalwala	50	20	3.586	0.896	0.689
Malowala	101	35	5.665	1.247	0.808
Mohund	35	21	4.047	1.124	0.85
Rasulpur	49	26	4.737	1.095	0.774
Sendhli	54	30	5.395	0.971	0.657
Sukh	100	44	7.168	1.379	0.839
Tira	55	22	3.893	0.955	0.712

n = Number of sampling points, N = Number of species.

Table 4.4 Tree density, girth at breast height (GBH) and tree height among different vegetation types in Rajaji Sanctuary.

Vegetation type	N	Density	GBH	C.L	Height	C.L
Mixed forest on plains	24	574	74.3	11.2	6.96	0.97
Sal forest on plains	99	544	90.4	4.7	9.74	0.57
Plantations	321	592	73.5	2.4	8.27	0.23
Sal mixed forest on hills	236	395	89.9	2.9	9.51	0.28
Sal forest on hills	77	510	86.6	4.6	9.76	0.42
Mixed forest on hills	548	377	84.8	2.2	8.88	0.20

N = Number of sampling points, C.L = 95% confidence intervals, GBH is in centimeters, Height is in meters, density is in hectare.

Table 4.5 Tree density, girth at breast height (GBH) and tree height among different terrain types in Rajaji Sanctuary.

Vegetation types	N	Density	GBH	C.L	Height	C.L
Flat	435	581	77.1	2.2	8.50	0.23
Undulating	58	410	104.7	9.0	10.51	0.64
Upper slopes	447	368	82.2	2.9	8.45	0.19
Lower slopes	318	433	88.6	2.7	9.75	0.26
Valleys	47	365	88.2	7.9	9.86	0.84

N = Number of sampling points, C.L = 95% confidence intervals, values of GBH are in centimeters and height are in meters.

Table 4.6 Tree density, girth at breast height (GBH) and tree height among different administrative units in Rajaji Sanctuary.

Forest Blocks	N	Density	GBH	C.L.	Height	C.L.
Andheri	100	355	88.6	4.2	9.58	0.38
Bam	101	318	87.8	5.1	9.44	0.54
Baniawala	49	428	91.9	4.1	9.22	0.66
Betban	99	489	90.7	5.2	9.23	0.43
Chillawala	101	396	90.1	5.2	9.28	0.46
Dholkhund	103	385	85.2	4.9	8.27	0.41
Gaaj	100	452	86.0	4.2	9.79	0.4
Ganjarban	56	605	67.7	6.7	6.77	0.67
Gholna	102	400	78.7	3.8	8.85	0.34
Lakkarkot	50	531	83.0	7.1	8.74	0.98
Lalwala	50	495	73.7	5.8	7.92	0.55
Malowala	101	406	78.5	4.5	8.35	0.45
Mohund	35	421	92.3	7.4	10.49	0.94
Rasulpur	49	361	87.4	5.8	9.28	0.67
Sendhli	54	878	63.8	6.4	8.05	0.44
Sukh	100	518	88.8	5.2	9.56	0.48
Tira	55	942	64.9	5.3	7.9	0.43

N = Number of sampling points, C.L = 95% confidence intervals, values of GBH are in centimeters and height are in meters.

Table 4.7 Sorenson's Similarity Index values for different vegetation types in Rajaji Sanctuary.

Vegetation types	MFH	SFH	SMFH	PL	SFP
SFH	0.45				
SMFH	0.76	0.52			
PL	0.75	0.46	0.62		
SFP	0.56	0.53	0.58	0.69	
MFP	0.62	0.45	0.68	0.63	0.62

SFH = Sal forest on hills, SMFH = Sal mixed forest on hills, PL = Plantations
SFP = Sal forest on plains, MFP = Mixed forest on plains, MFH = Mixed forest on hills.

Table 4.8 Density, percentage and Importance Value Index (IVI) of tree species in mixed forest on plains.

Tree species	Density	%	Cum. %	IVI
Mallotus philippensis	114	19.79	19.79	45.10
Ehretia laevis	72	12.50	32.29	35.17
Lagerstroemia parviflora	48	8.33	40.62	23.37
Shorea robusta	24	4.17	44.79	23.16
Acacia catechu	36	6.25	51.04	19.25
Kydia calycina	36	6.25	57.29	16.08
Miliusa velutina	24	4.17	61.46	12.13
Firmiana fulgens	12	2.08	63.54	10.85
Terminalia alata	12	2.08	65.62	10.40
Dalbergia sissoo	18	3.13	68.75	9.70
Aegle marmelos	18	3.13	71.87	9.08
Xeromphis spinosa	18	3.13	75.00	8.12
Holarrhena pubescens	18	3.13	78.12	7.80
Lannea coromandelica	6	1.04	79.17	7.72
Ficus rumphii	6	1.04	80.21	6.16
Litsea glutinosa	12	2.08	82.29	5.74
Ziziphus xylopyra	18	3.13	85.42	5.36
Terminalia bellirica	6	1.04	86.46	4.16
Grewia elastica	6	1.04	87.50	3.84
Bridelia squamosa	6	1.04	88.54	3.78
Hymenodictyon orixense	6	1.04	89.58	3.43
Bauhinia purpurea	6	1.04	90.62	3.38
Schleichera oleosa	6	1.04	91.67	3.24
Ailanthus excelsa	6	1.04	92.71	3.23

Butea monosperma	6	1.04	93.75	3.17
Holoptelea integrifolia	6	1.04	94.79	2.93
Flacourtia indica	6	1.04	95.83	2.82
Cordia dichotoma	6	1.04	96.87	2.79
Gardenia turgida	6	1.04	97.92	2.69
Naringi crenulata	6	1.04	98.96	2.67
Cassia fistula	6	1.04	100.00	2.64

% = Density percentage, Cum.% = Cumulative percentage,
No. of sampling points = 24.

Table 4.9 Density, percentage and Importance Value Index (IVI) of tree species in Sal forest on plains.

Tree species	Density	%	Cum. %	IVI
Shorea robusta	301	55.54	55.54	175.06
Ehretia laevis	47	8.67	64.21	24.72
Mallotus philippensis	51	9.41	73.62	22.92
Lagerstroemia parviflora	48	8.86	82.48	21.79
Miliusa velutina	22	4.06	86.54	11.65
Ziziphus xylopyra	11	2.03	88.57	5.41
Ougeinia oogeinsis	6	1.11	89.67	3.49
Acacia catechu	7	1.29	90.96	3.23
Anogeissus latifolia	4	0.74	91.70	3.11
Holarrhena pubescens	6	1.11	92.81	2.96
Tectona grandis	4	0.74	93.55	2.76
Butea monosperma	4	0.74	94.29	2.35
Terminalia alata	3	0.55	94.84	2.22
Bauhinia malabarica	4	0.74	95.58	2.03
Kydia calycina	3	0.55	96.13	1.71
Garuga pinnata	3	0.55	96.68	1.70
Grewia elastica	3	0.55	97.24	1.64
Lannea coromandelica	3	0.55	97.79	1.53
Mitragyna parvifolia	1	0.18	97.98	1.04
Bauhinia purpurea	1	0.18	98.16	1.04
Haldina cordifolia	1	0.18	98.34	0.85
Ficus religiosa	1	0.18	98.53	0.83
Dalbergia sissoo	1	0.18	98.71	0.80
Stereospermum chelonoides	1	0.18	98.90	0.80

Gardenia turgida	1	0.18	99.08	0.75
Ailanthus excelsa	1	0.18	99.27	0.74
Cordia dichotoma	1	0.18	99.45	0.73
Ziziphus mauritiana	1	0.18	99.64	0.73
Aegle marmelos	1	0.18	99.82	0.73
Gmelina arborea	1	0.18	100.00	0.70

% = Density percentage, Cum.% = Cumulative percentage.
No. of sampling points = 99

Table 4.10 Density, percentage and Importance Value Index (IVI) of tree species in plantations.

Tree species	Density	%	Cum. %	IVI
Acacia catechu	98	16.50	16.50	36.88
Dalbergia sissoo	88	14.81	31.31	34.17
Ailanthus excelsa	81	13.64	44.95	29.05
Tectona grandis	83	13.97	58.92	25.66
Mallotus philippensis	50	8.42	67.34	19.77
Kydia calycina	25	4.21	71.55	10.92
Bombax ceiba	27	4.55	76.10	9.65
Holoptelea integrifolia	14	2.36	78.45	6.15
Ehretia laevis	14	2.36	80.81	5.37
Lagerstroemia parviflora	11	1.85	82.66	4.19
Shorea robusta	6	1.01	83.67	3.44
Terminalia bellirica	6	1.01	84.68	3.03
Casearia elliptica	7	1.18	85.86	2.97
Miliusa velutina	6	1.01	86.87	2.40
Bauhinia malabarica	6	1.01	87.88	2.34
Butea monosperma	5	0.84	88.72	2.32
Cassia fistula	5	0.84	89.56	2.22
Bauhinia purpurea	5	0.84	90.41	1.97
Holarrhena pubescens	4	0.67	91.08	1.79
Anogeissus latifolia	3	0.51	91.58	1.73
Albizia odoratissima	4	0.67	92.26	1.71
Garuga pinnata	4	0.67	92.93	1.66
Bauhinia variegata	3	0.51	93.44	1.59
Ziziphus xylopyra	4	0.67	94.11	1.55
Morus alba	3	0.51	94.61	1.36

Litsea glutinosa	3	0.51	95.12	1.23
Xeromphis spinosa	2	0.34	95.46	1.17
Grewia elastica	2	0.34	95.79	1.08
Flacourtia indica	2	0.34	96.13	1.01
Mitragyna parvifolia	2	0.34	96.47	0.99
Emblica officinalis	1	0.17	96.63	0.73
Lannea coromandelica	1	0.17	96.80	0.70
Azadirachta indica	1	0.17	96.97	0.70
Stereospermum chelonoides	1	0.17	97.14	0.66
Terminalia alata	1	0.17	97.31	0.65
Premna barbata	1	0.17	97.48	0.58
Aegle marmelos	1	0.17	97.64	0.55
Gmelina arborea	1	0.17	97.81	0.54
Haldina cordifolia	1	0.17	97.98	0.52
Hymenodictyon orixense	1	0.17	98.15	0.51
Moringa oleifera	1	0.17	98.32	0.46
Bridelia squamosa	1	0.17	98.49	0.46
Ziziphus mauritiana	1	0.17	98.65	0.43
Grewia optiva	1	0.17	98.82	0.35
Firmiana fulgens	1	0.17	98.99	0.26
Streblus asper	1	0.17	99.16	0.25
Ougeinia oogeinsis	1	0.17	99.33	0.24
Albizia procera	1	0.17	99.50	0.23
Erythrina suberosa	1	0.17	99.66	0.23
Wrightia arborea	1	0.17	99.83	0.22
Ficus religiosa	1	0.17	100.00	0.21

% = Density percentage, Cum.% = Cumulative percentage.
No. of sampling points = 321

Table 4.11 Density, percentage and Importance Value Index (IVI) of tree species in Sal mixed forest on hills.

Tree species	Density	%	Cum. %	IVI
Shorea robusta	142.74	36.23	36.23	109.77
Anogeissus latifolia	48.83	12.39	48.62	37.27
Terminalia alata	36.73	9.32	57.95	33.18
Ougeinia oogeinsis	37.15	9.43	67.37	27.66
Pinus roxburghii	21.29	5.40	72.78	17.59
Buchanania lanzan	17.95	4.56	77.33	13.14
Acacia catechu	13.36	3.39	80.72	8.80
Bauhinia purpurea	9.18	2.33	83.05	6.35
Ziziphus xylopyra	7.93	2.01	85.06	5.00
Mallotus philippensis	8.35	2.12	87.18	4.78
Lagerstroemia parviflora	6.68	1.69	88.88	4.60
Ehretia laevis	6.68	1.69	90.57	4.37
Kydia calycina	6.26	1.59	92.16	4.03
Terminalia bellirica	1.67	0.42	92.59	1.65
Emblica officinalis	2.50	0.64	93.22	1.63
Lannea coromandelica	2.09	0.53	93.75	1.61
Litsea glutinosa	2.09	0.53	94.28	1.37
Flacourtia indica	1.67	0.42	94.70	1.34
Syzygium cerasoides	1.25	0.32	95.02	1.18
Cassia fistula	1.67	0.42	95.45	1.13
Gardenia turgida	1.67	0.42	95.87	1.12
Bauhinia malabarica	1.67	0.42	96.29	1.10
Grewia elastica	1.67	0.42	96.72	1.04
Garuga pinnata	1.25	0.32	97.04	1.04

Cordia dichotoma	1.25	0.32	97.35	0.92
Stereospermum chelonoides	0.83	0.21	97.56	0.69
Syzygium cumini	0.83	0.21	97.78	0.61
Ficus rumphii	0.83	0.21	97.99	0.60
Ficus religiosa	0.42	0.11	98.09	0.59
Bridelia squamosa	0.83	0.21	98.31	0.58
Miliusa velutina	0.83	0.21	98.52	0.58
Casearia elliptica	0.83	0.21	98.73	0.55
Firmiana fulgens	0.83	0.21	98.94	0.55
Bombax ceiba	0.42	0.11	99.05	0.54
Holarrhena pubescens	0.83	0.21	99.26	0.52
Holoptelea integrifolia	0.42	0.11	99.37	0.46
Cordia vestita	0.42	0.11	99.47	0.41
Careya arborea	0.42	0.11	99.58	0.38
Schleichera oleosa	0.42	0.11	99.68	0.36
Albizia procera	0.42	0.11	99.79	0.33
Dalbergia sissoo	0.42	0.11	99.90	0.30
Ficus benghalensis	0.42	0.11	100.00	0.29

% = Density percentage, Cum.% = Cumulative percentage.
No. of sampling points = 236

Table 4.12 Density, percentage and Importance Value Index (IVI) of tree species in Sal forest on hills.

Tree species	Density	%	Cum. %	IVI
Shorea robusta	286	55.86	55.86	161.78
Anogeissus latifolia	43	8.40	64.26	27.80
Ougeinia oogeinsis	38	7.42	71.68	24.94
Terminalia alata	36	7.03	78.71	24.50
Buchanania lanzan	17	3.32	82.03	10.04
Mallotus philippensis	22	4.30	86.33	9.58
Ehretia laevis	13	2.54	88.87	6.00
Lagerstroemia parviflora	8	1.56	90.43	4.46
Bauhinia purpurea	7	1.37	91.80	4.23
Kydia calycina	8	1.56	93.36	4.14
Acacia catechu	7	1.37	94.73	4.08
Haldina cordifolia	3	0.59	95.31	3.70
Bauhinia malabarica	5	0.98	96.29	3.05
Grewia elastica	3	0.59	96.88	2.04
Firmiana fulgens	2	0.39	97.27	1.77
Pinus roxburghii	2	0.39	97.66	1.30
Garuga pinnata	2	0.39	98.05	1.26
Cordia vestita	2	0.39	98.44	1.22
Stereospermum chelonoides	2	0.39	98.83	1.10
Cassia fistula	2	0.39	99.22	1.04
Melia azedarach	2	0.39	99.61	1.02
Ziziphus xylopyra	2	0.39	100.00	0.92

% = Density percentage, Cum.% = Cumulative percentage.
No. of sampling points = 77

Table 4.13 Density, percentage and Importance Value Index (IVI) of tree species in mixed forest on hills.

Tree species	Density	%	Cum. %	IVI
Anogeissus latifolia	67.76	17.97	17.97	53.25
Shorea robusta	33.88	8.99	26.96	29.89
Ougeinia oogeinsis	31.65	8.39	35.35	22.09
Acacia catechu	29.93	7.94	43.29	21.94
Terminalia alata	22.70	6.02	49.31	21.22
Pinus roxburghii	22.01	5.84	55.15	19.58
Bauhinia purpurea	21.50	5.70	60.85	15.34
Buchanania lanzan	12.90	3.42	64.27	9.88
Ziziphus xylopyra	14.28	3.79	68.06	8.80
Ehretia laevis	11.52	3.06	71.12	7.81
Kydia calycina	8.77	2.33	73.44	5.58
Cassia fistula	7.22	1.92	75.36	4.85
Mallotus philippensis	7.05	1.87	77.23	4.81
Grewia elastica	6.54	1.73	78.96	4.32
Lagerstroemia parviflora	5.68	1.51	80.47	4.26
Lannea coromandelica	3.61	0.96	81.43	3.81
Syzygium cerasoides	4.13	1.09	82.52	3.81
Dalbergia sissoo	4.47	1.19	83.71	3.55
Garuga pinnata	3.78	1.00	84.71	3.45
Ficus racemosa	1.20	0.32	85.03	3.00
Terminalia bellirica	2.58	0.68	85.72	2.90
Stereospermum chelonoides	3.78	1.00	86.72	2.83
Mitragyna parvifolia	1.72	0.46	87.18	2.73
Bauhinia malabarica	4.13	1.09	88.27	2.63

Holarrhena pubescens	3.96	1.05	89.32	2.44
Casearia elliptica	2.92	0.78	90.10	2.29
Bombax ceiba	1.20	0.32	90.42	2.20
Gardenia turgida	3.27	0.87	91.28	2.17
Albizia odoratissima	2.58	0.68	91.97	1.91
Cordia dichotoma	2.24	0.59	92.56	1.88
Litsea glutinosa	2.24	0.59	93.15	1.79
Emblica officinalis	2.06	0.55	93.70	1.63
Cordia vestita	2.06	0.55	94.25	1.43
Ficus religiosa	0.52	0.14	94.38	1.34
Miliusa velutina	1.89	0.50	94.89	1.33
Haldina cordifolia	0.69	0.18	95.07	1.33
Schleichera oleosa	1.38	0.36	95.43	1.31
Flacourtia indica	1.38	0.36	95.80	1.18
Aegle marmelos	1.55	0.41	96.21	1.15
Casearia elliptica	1.20	0.32	96.53	1.08
Naringi crenulata	1.72	0.46	96.98	0.98
Firmiana fulgens	0.86	0.23	97.21	0.97
Ficus benghalensis	0.34	0.09	97.30	0.88
Grewia hainesiana	1.03	0.27	97.58	0.81
Nyctanthes arbor-tristis	0.86	0.23	97.81	0.61
Butea monosperma	0.69	0.18	97.99	0.61
Grewia optiva	0.86	0.23	98.22	0.59
Wrightia arborea	0.69	0.18	98.40	0.53
Syzygium cumini	0.34	0.09	98.49	0.51
Holoptelea integrifolia	0.52	0.14	98.63	0.50
Premna barbata	0.52	0.14	98.76	0.49
Ailanthus excelsa	0.69	0.18	98.95	0.48

Albizia lebbeck	0.34	0.09	99.04	0.37
Erythrina suberosa	0.34	0.09	99.13	0.37
Xeromphis spinosa	0.52	0.14	99.27	0.31
Careya arborea	0.34	0.09	99.36	0.31
Bridelia squamosa	0.34	0.09	99.45	0.29
Ziziphus mauritiana	0.52	0.14	99.58	0.28
Tectona grandis	0.34	0.09	99.68	0.25
Artocarpus lakoocha	0.34	0.09	99.77	0.25
Albizia procera	0.17	0.05	99.81	0.25
Anthocephalus chinensis	0.17	0.05	99.86	0.15
Melia azedarach	0.17	0.05	99.90	0.15
Bauhinia variegata	0.17	0.05	99.95	0.14
Hymenodictyon orixense	0.17	0.05	100.00	0.13

% = Density percentage, Cum.% = Cumulative percentage.
No. of sampling points = 548

Table 4.14 Percentage of lopped trees, proportion available (P_{io}), proportion lopped (P_{ie}) and 95% confidence intervals for different administrative units of Rajaji Sanctuary.

Forest Block	N	NL	%	P_{io}	P_{ie}	95% confidence interval			Sig.
						Lower Limit		Upper Limit	
Andheri	400	73	18.3	0.083	0.05	0.033	$\leq P1 \geq$	0.066	-
Bam	404	193	47.8	0.084	0.131	0.105	$\leq P2 \geq$	0.157	+
Baniawala	196	47	24.0	0.041	0.032	0.018	$\leq P3 \geq$	0.045	0
Betban	396	189	47.7	0.082	0.128	0.103	$\leq P4 \geq$	0.154	+
Chillawala	404	186	46.0	0.084	0.126	0.101	$\leq P5 \geq$	0.152	+
Gaaj	400	111	27.8	0.083	0.075	0.055	$\leq P6 \geq$	0.096	0
Ganjarban	224	45	20.1	0.047	0.031	0.017	$\leq P7 \geq$	0.044	-
Gholna	408	225	55.1	0.085	0.153	0.125	$\leq P8 \geq$	0.18	+
Lakkarkot	200	22	11.0	0.042	0.015	0.006	$\leq P9 \geq$	0.024	-
Lalwala	200	74	37.0	0.042	0.05	0.033	$\leq P10 \geq$	0.067	0
Malowala	404	46	11.4	0.084	0.031	0.018	$\leq P11 \geq$	0.045	-
Mohund	140	1	0.7	0.029	0.001	-0.001	$\leq P12 \geq$	0.003	-

Rasulpur	196	33	16.8	0.041	0.022	0.011	$\leq$P13$\geq$	0.034	-
Sendhli	216	35	16.2	0.045	0.024	0.012	$\leq$P14$\geq$	0.035	-
Sukh	404	155	38.4	0.084	0.105	0.082	$\leq$P15$\geq$	0.129	0
Tira	220	39	17.7	0.046	0.026	0.014	$\leq$P16$\geq$	0.039	-

N= No. of trees sampled, NL= No. of trees lopped, Sig. = Significance level
0= lopping proportional to availability, - significantly lower lopping, + = significantly higher lopping.

Table 4.15 Proportion available (P_{io}), proportion lopped (P_{ie}) and 95% confidence intervals for lopped tree species.

Tree species	N	NL	P_{io}	P_{ie}	95% confidence interval			Sig.
					Lower Limit		Upper Limit	
Anogeissus latifolia	547	392	0.1595	0.2753	0.2388	$\leq P1 \geq$	0.3117	+
Terminalia alata	249	172	0.0726	0.1208	0.0942	$\leq P2 \geq$	0.1474	+
Ougeinia oogeinsis	301	162	0.0878	0.1138	0.0878	$\leq P3 \geq$	0.1397	+
Acacia catechu	434	144	0.1265	0.1011	0.0765	$\leq P4 \geq$	0.1257	-
Ailanthus excelsa	172	100	0.0501	0.0702	0.0494	$\leq P5 \geq$	0.0911	0
Bauhinia purpurea	163	92	0.0475	0.0646	0.0445	$\leq P6 \geq$	0.0847	0
Kydia calycina	133	70	0.0388	0.0492	0.0315	$\leq P7 \geq$	0.0668	0
Grewia elastica	52	45	0.0152	0.0316	0.0173	$\leq P8 \geq$	0.0459	+
Shorea robusta	949	34	0.2767	0.0239	0.0114	$\leq P9 \geq$	0.0363	-
Miliusa velutina	45	31	0.0131	0.0218	0.0099	$\leq P10 \geq$	0.0337	0
Terminalia bellirica	34	27	0.0099	0.019	0.0078	$\leq P11 \geq$	0.0301	0
Bauhinia malabarica	46	24	0.0085	0.0169	0.0063	$\leq P12 \geq$	0.0274	0
Stereospermum chelonoides	29	24	0.0134	0.0169	0.0063	$\leq P13 \geq$	0.0274	0

Ziziphus xylopyra	122	19	0.0356	0.0133	0.004	≤P14≥	0.0227	-
Litsea glutinosa	26	17	0.0076	0.0119	0.0031	≤P15≥	0.0208	0
Garuga pinnata	36	16	0.0105	0.0112	0.0026	≤P16≥	0.0198	0
Mitragyna parvifolia	16	14	0.0047	0.0098	0.0018	≤P17≥	0.0179	0
Schleichera oleosa	10	10	0.0029	0.007	0.0002	≤P18≥	0.0138	0
Albizia odoratissima	23	9	0.0067	0.0063	0.0000	≤P19≥	0.0128	0
Bauhinia variegata	8	7	0.0061	0.0049	0.0000	≤P20≥	0.0106	0
Emblica officinalis	21	7	0.0023	0.0049	0.0000	≤P21≥	0.0106	0
Bridelia squamosa	7	5	0.002	0.0035	0.0000	≤P22≥	0.0083	0
Grewia optiva	7	5	0.002	0.0035	0.0000	≤P23≥	0.0083	0

N= No. of trees sampled, NL= No. of trees lopped, 0= lopping proportional to availability, - significantly lower lopping, + = significantly higher lopping. Sig. = Significance level

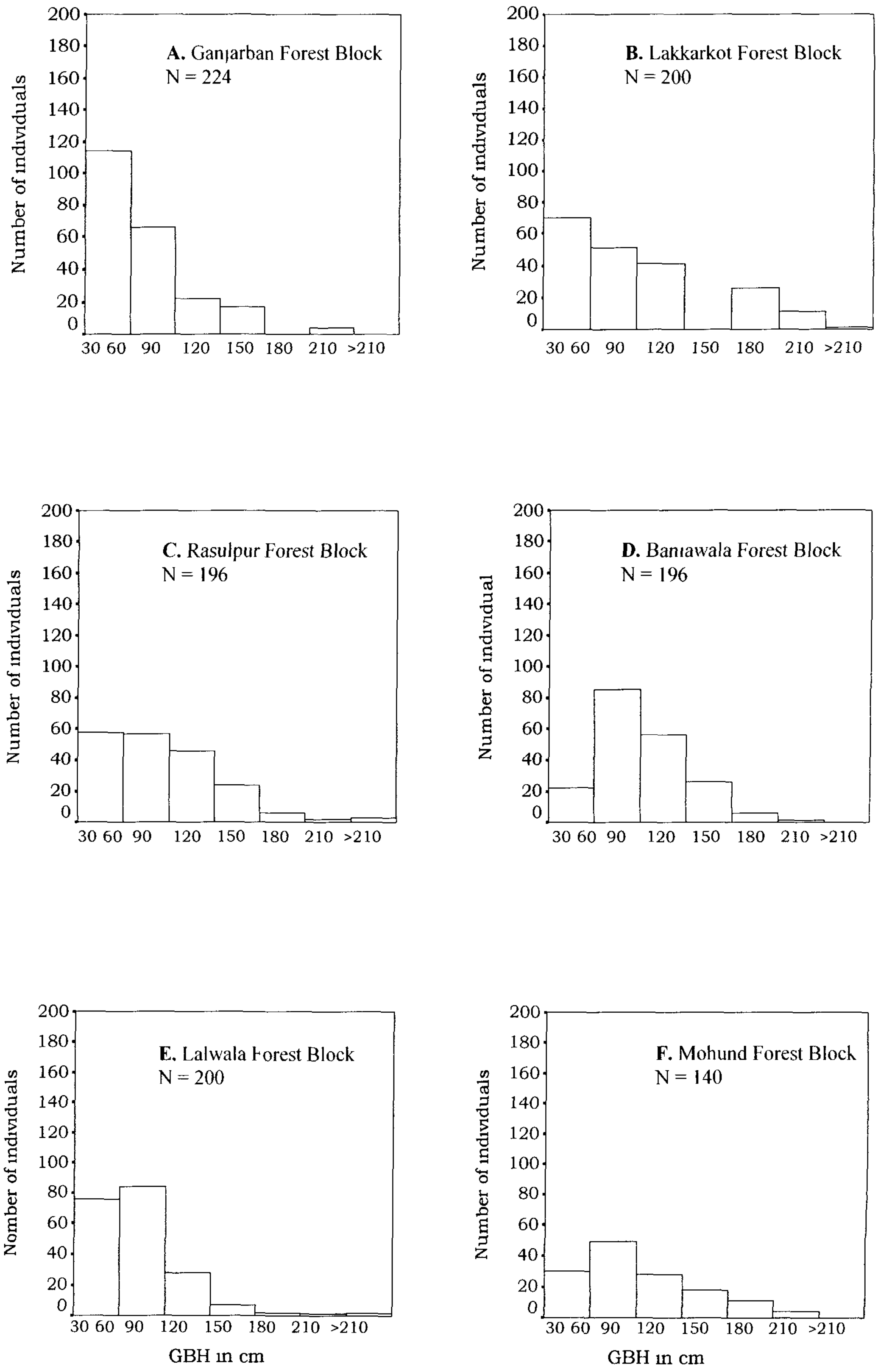


Fig. 4.2 Tree population structure in different Forest Blocks of Rajaji.

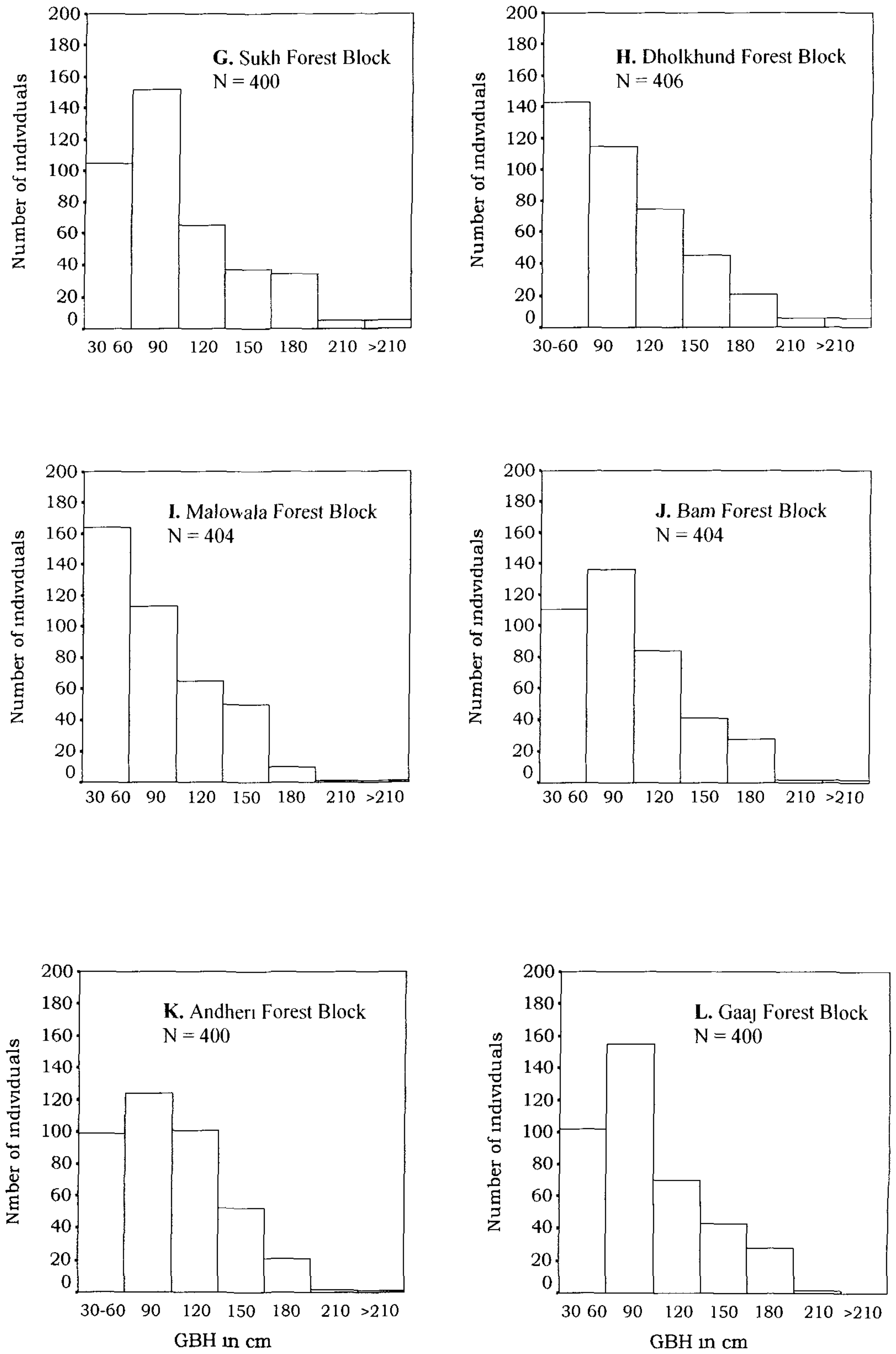


Fig. 4.2 Tree population structure in different Forest Blocks of Rajaji.

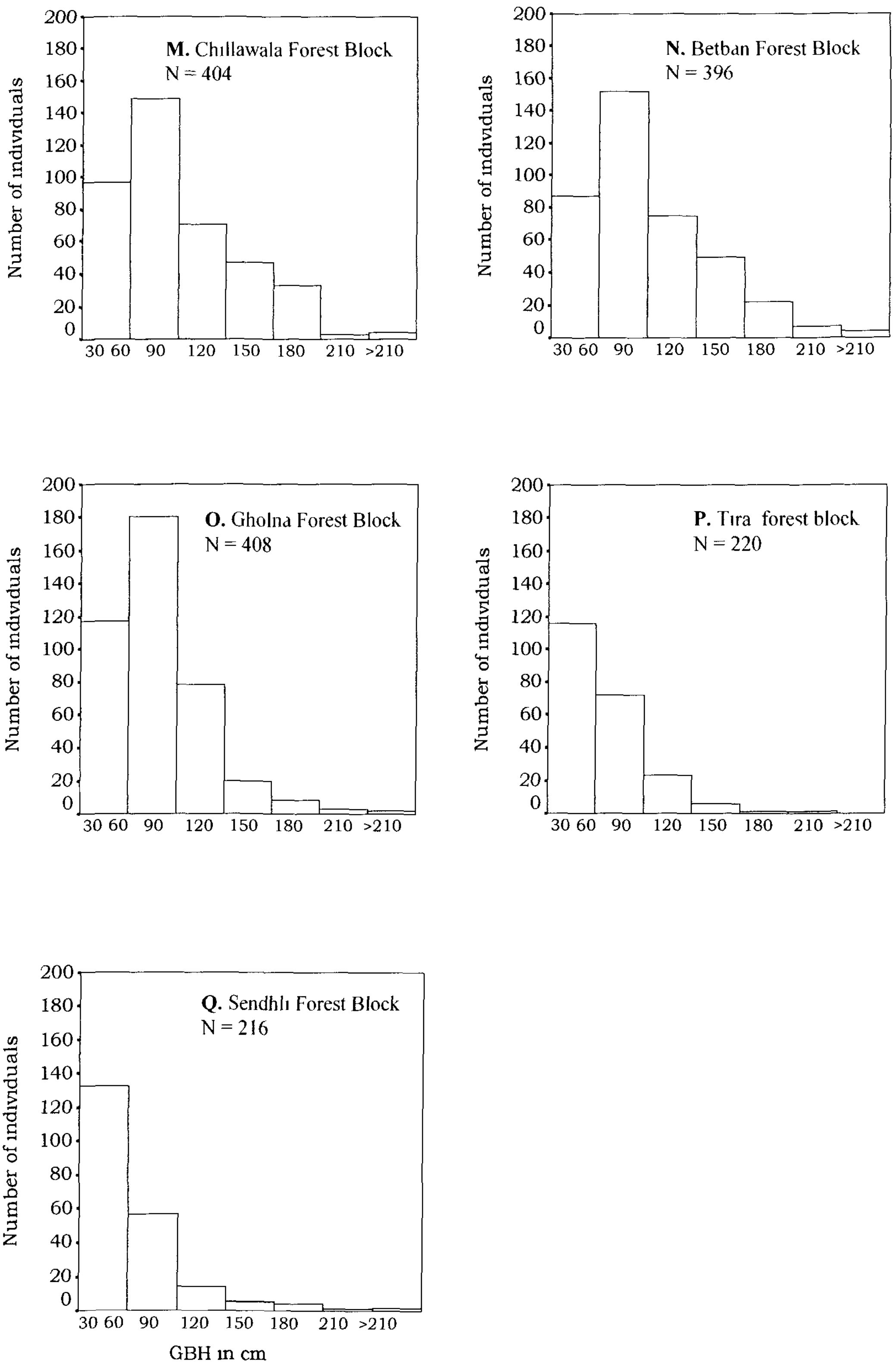
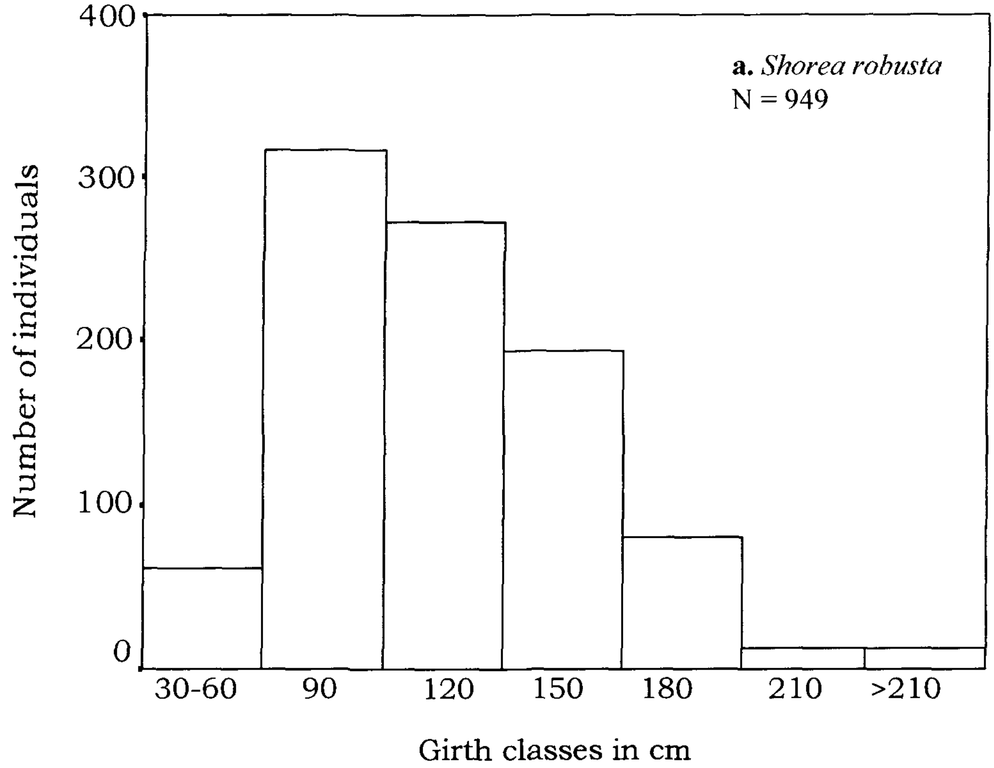


Fig. 4.2 Tree population structure in different Forest Blocks of Rajaji.



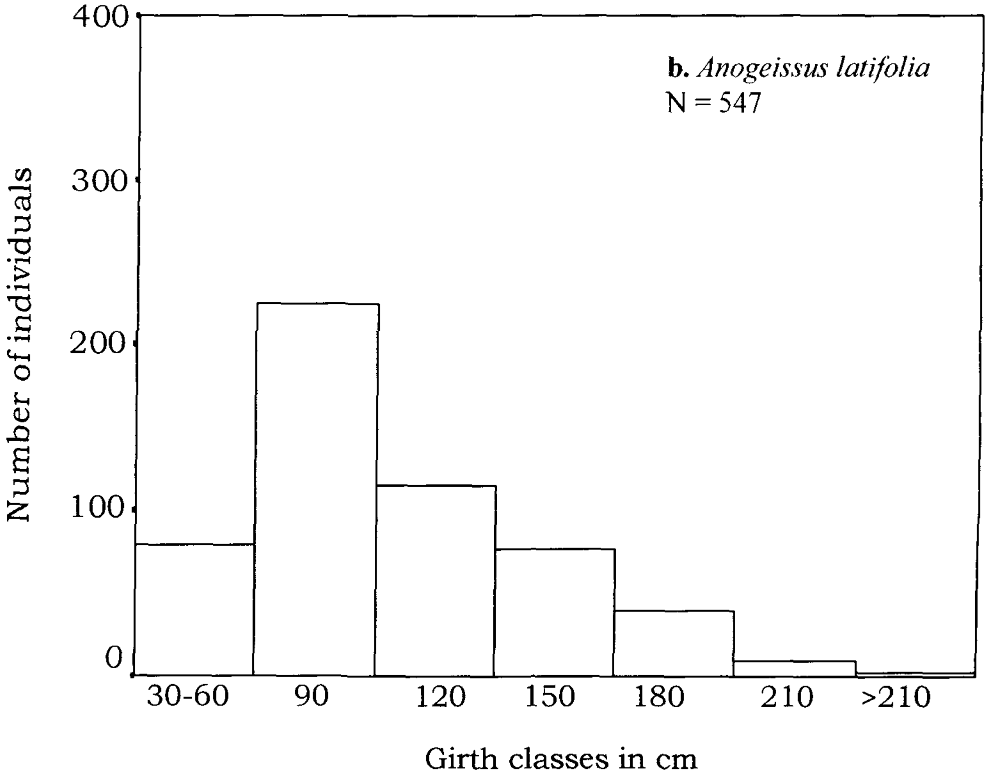
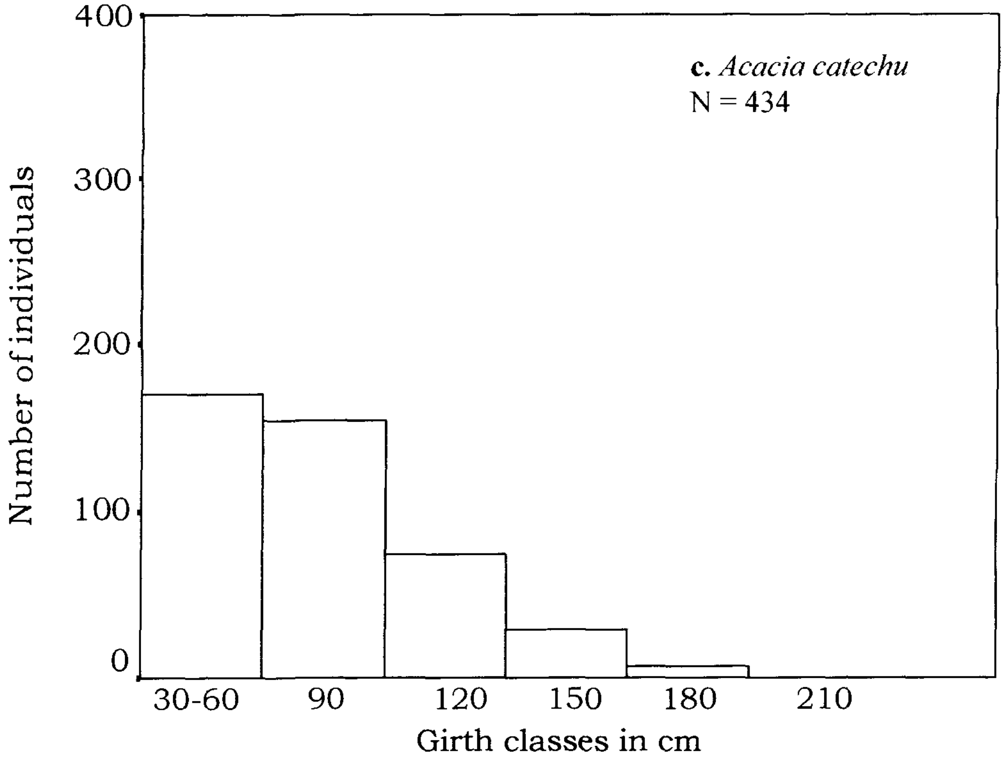


Fig. 4.3 Population structures of dominant tree species in Rajaji.



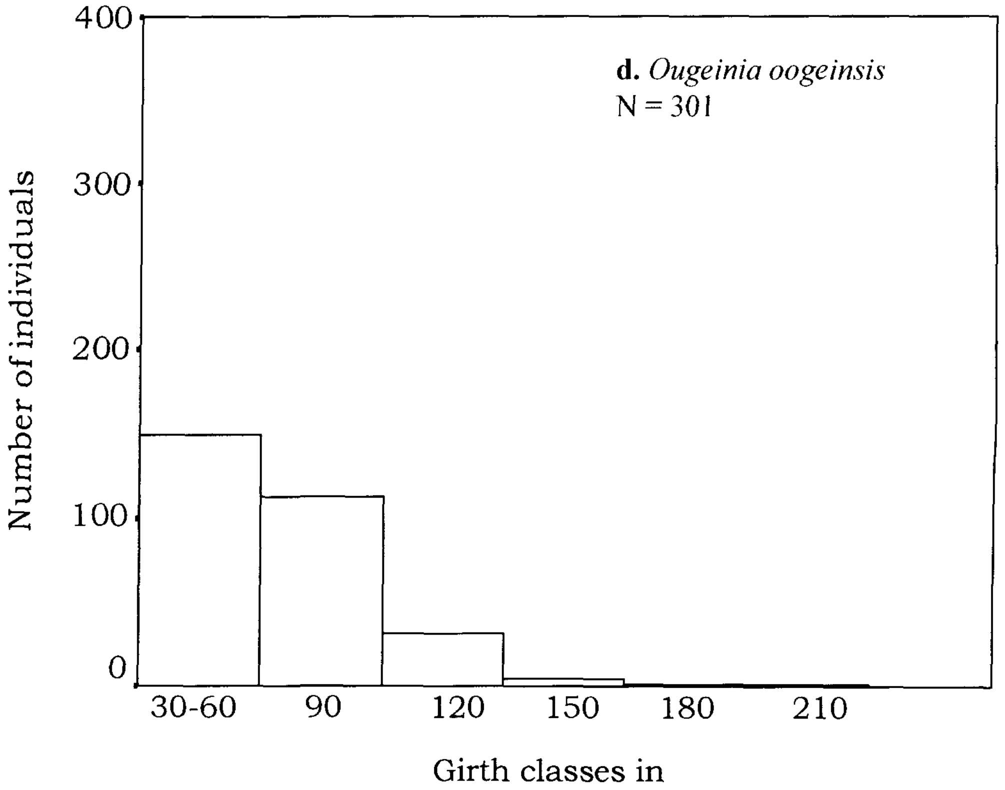
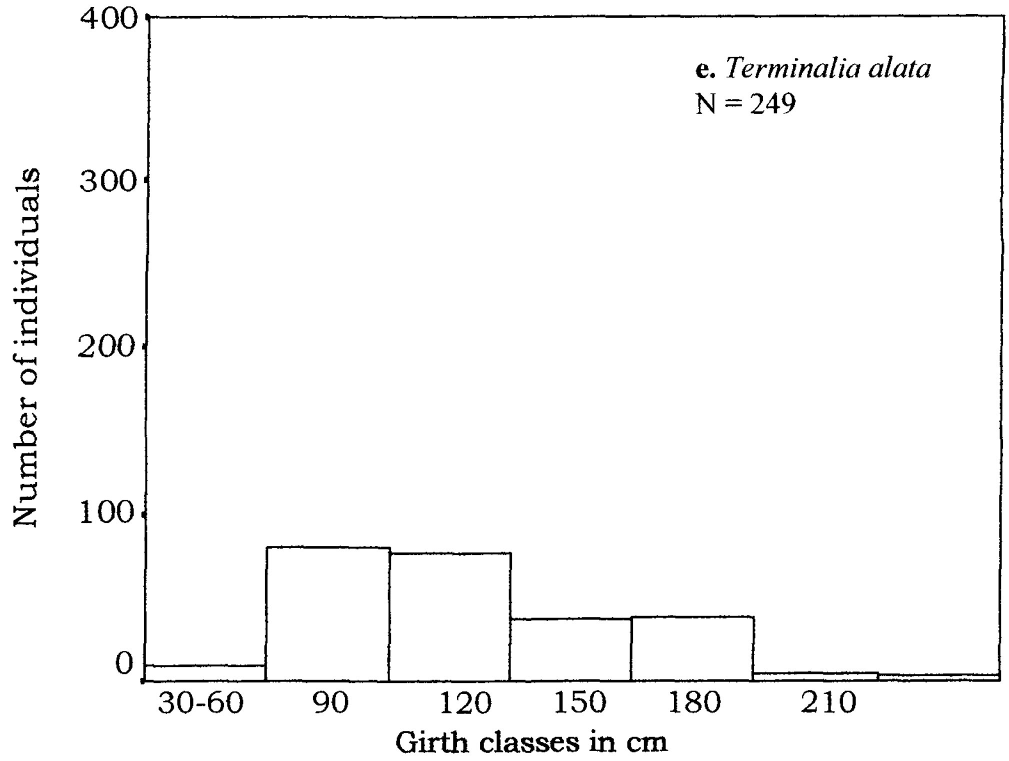


Fig. 4.3 Population structures of dominant tree species in Rajaji.



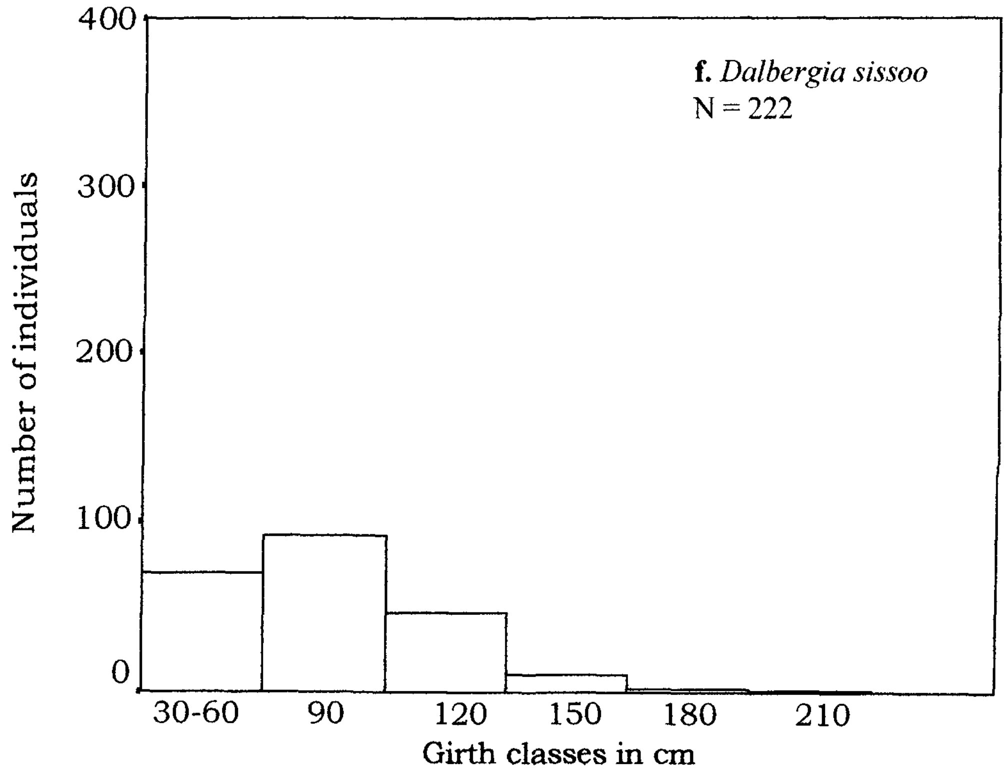


Fig. 4.3 Population structures of dominant tree species in Rajaji.

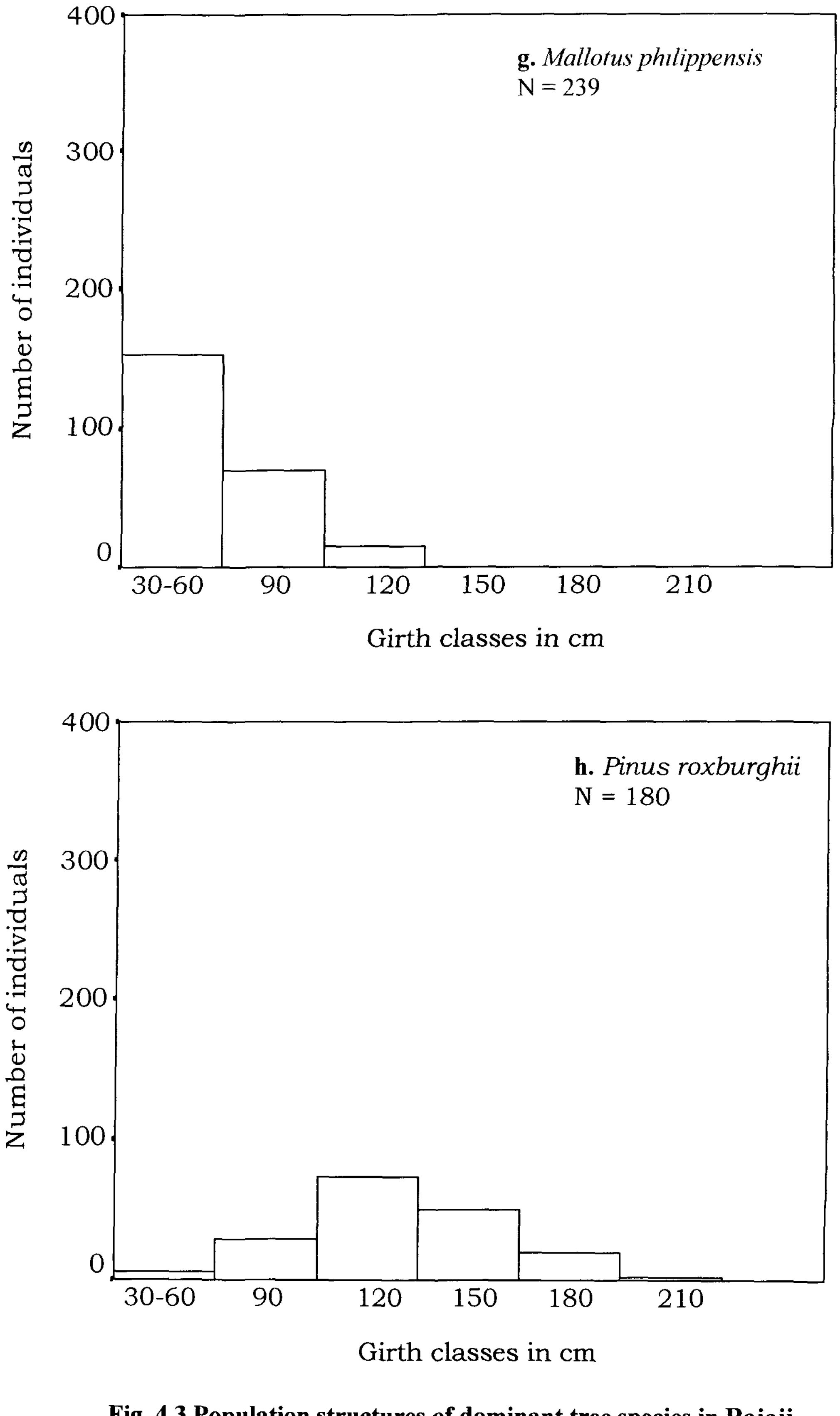
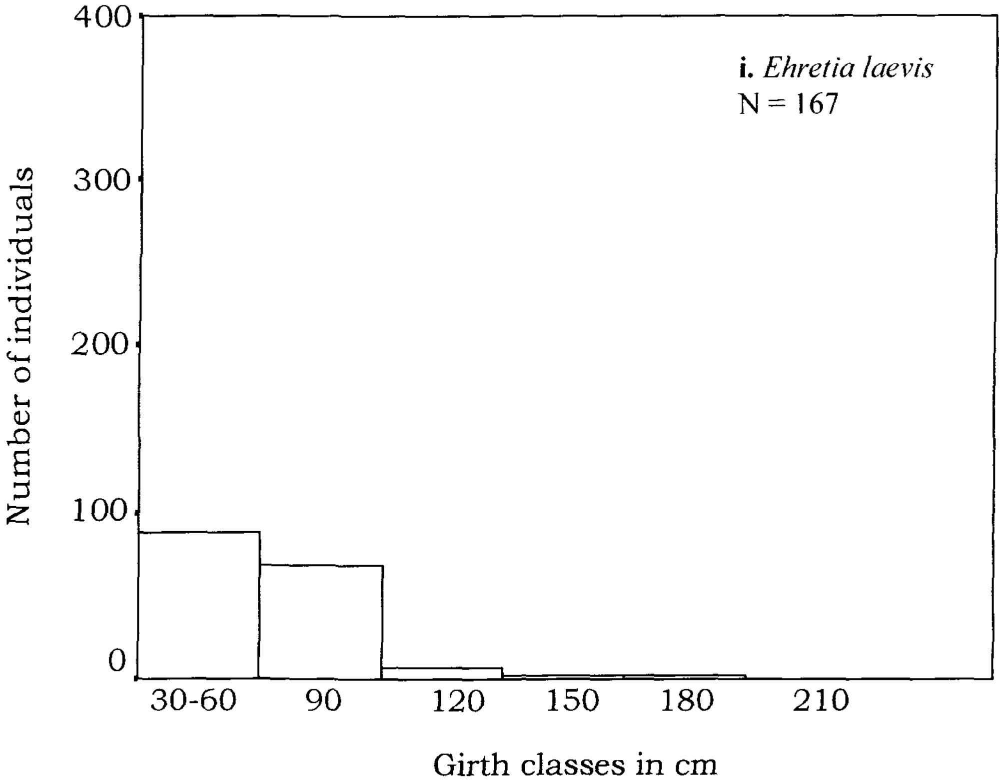


Fig. 4.3 Population structures of dominant tree species in Rajaji.



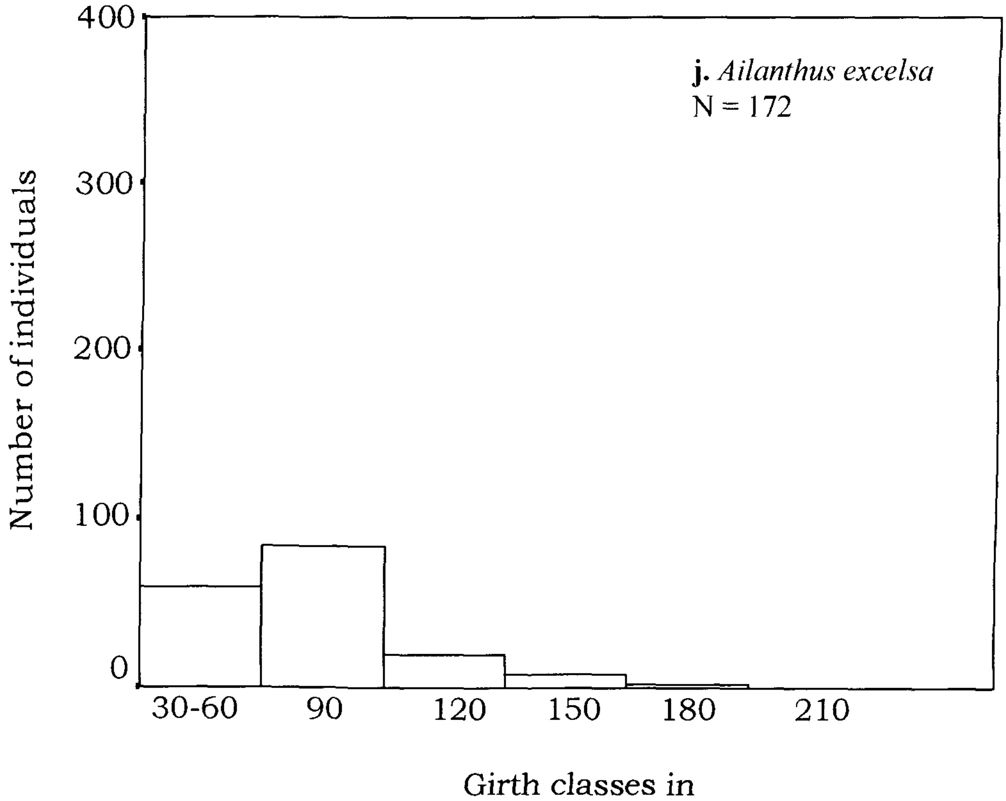


Fig. 4.3 Population structures of dominant tree species in Rajaji.

Table 4.16 Mean density, species richness, diversity and evenness of shrubs among different vegetation types in Rajaji.

Vegetation types	n	N	Density	Richness	Diversity	Evenness
Mixed forest on plains	24	16	3633	3.286	1.008	0.837
Sal forest on plains	96	24	3790	3.865	0.866	0.627
Plantations	262	23	3116	3.163	0.757	0.556
Sal mixed forest on hills	187	25	1817	3.627	1.126	0.806
Sal forest on hills	64	16	1989	2.705	0.974	0.809
Mixed forest on hills	451	42	1708	5,468	1.194	0.735

n = Number of sampling points, N = No. of species, density is in hectare.

Table 4.17 Mean density, species richness, diversity and evenness of shrubs among different terrain types in Rajaji .

Terrain types	n	N	Density	Richness	Diversity	Evenness
Flat	373	28	3243	3.695	0.915	0.632
Undulating	58	14	3189	2.387	0.802	0.7
Upper slopes	330	36	1486	4.87	1.222	0.785
Lower slopes	283	35	2106	4.835	1.075	0.696
Valleys	40	20	1370	3.744	1.104	0.849

n = Number of sampling points, N = No. of species, C.L = Confidence limit, data at 95% confidence interval, density is in hectare.

Table 4.18 Shrub density (D1), weed density (D2), percentage of weeds (%D2), proportion of shrubs (P_{io}) Proportion of weeds (P_{ie}) and 95% confidence intervals in different administrative units of Rajaji Sanctuary.

Forest Blocks	D1	D2	%D2	P_{io}	P_{ie}	95% confidence interval Lower limit		Upper limit	Sig. Level
Andheri	1766	190	10.75	0.0766	0.0349	0.0193	≤P1≥	0.0504	-
Bam	1814	18	0.99	0.0773	0.0032	-0.0016	≤P2≥	0.0081	-
Baniawala	5043	4683	92.86	0.0375	0.1476	0.1175	≤P3≥	0.1777	+
Betban	2298	279	12.12	0.0758	0.0389	0.0225	≤P4≥	0.0553	-
Chillawala	1623	386	23.76	0.0773	0.0779	0.0551	≤P5≥	0.1006	0
Dholkhund	1565	194	12.38	0.0789	0.0414	0.0245	≤P6≥	0.0583	-
Gaaj	2228	607	27.25	0.0766	0.0884	0.0643	≤P7≥	0.1125	0
Ganjarban	3175	907	28.57	0.0429	0.0519	0.0331	≤P8≥	0.0707	0
Gholna	1382	295	21.32	0.0781	0.0706	0.0488	≤P9≥	0.0923	0
Lakkarkot	4241	573	13.50	0.0383	0.0219	0.0095	≤P10≥	0.0343	-
Lalwala	3266	2874	88.00	0.0383	0.1427	0.1131	≤P11≥	0.1724	+
Malowala	1856	161	8.66	0.0773	0.0284	0.0143	≤P12≥	0.0425	-
Mohund	2799	880	31.43	0.0268	0.0357	0.0199	≤P13≥	0.0514	0

Rasulpur	2304	623	27.04	0.0375	0.043	0.0258	≤P14≥	0.0602	0
Sendhli	2507	58	2.31	0.0413	0.0041	-0.0013	≤P15≥	0.0094	–
Sukh	2113	633	29.95	0.0773	0.0981	0.0729	≤P16≥	0.1234	0
Tira	3169	1268	40.00	0.0421	0.0714	0.0495	≤P17≥	0.0932	+

0=Occurrence of weeds is proportional to occurrence of non weed shrubs, - occurrence of weeds significantly lower than the occurrence of non weed shrubs, + = occurrence of weeds significantly higher than the occurrence of non weed shrubs, Sig. = Significance level.

Table 4.19 Density (individuals/ha), percentage and cumulative percentage (Cum. %) of shrubs in mixed forest on plains.

Plant species	Density	%	Cum. %
Mallotus philippensis	681	18.74	18.74
Lantana camara	681	18.74	37.48
Murraya koenigii	530	14.49	51.97
Helicteres isora	454	12.50	64.47
Holarrhena pubescens	341	9.39	73.86
Adhatoda zeylanica	227	6.25	80.11
Lagerstroemia parviflora	114	3.14	83.25
Aegle marmelos	114	3.14	86.39
Carissa opaca	114	3.14	89.53
Millettia extensa	76	2.09	91.62
Ziziphus oenoplia	76	2.09	93.71
Tectona grandis	76	2.09	95.80
Miliusa velutina	38	1.05	96.85
Butea monosperma	38	1.05	97.90
Ehretia laevis	38	1.05	98.95
Cassia fistula	38	1.05	100

No. of sampling points = 24

Table 4.20 Density (individuals/ha), percentage and cumulative percentage (Cum. %) of shrubs in Sal forest on plains.

Plant species	Density	%	Cum. %
Mallotus philippensis	1836	48.48	48.48
Holarrhena pubescens	464	12.25	60.73
Millettia extensa	247	6.52	67.25
Lagerstroemia parviflora	188	4.96	72.21
Adhatoda zeylanica	178	4.69	76.9
Ehretia laevis	178	4.69	81.59
Helicteres isora	158	4.16	85.75
Miliusa velutina	109	2.86	88.61
Lantana camara	69	1.83	90.44
Cassia fistula	49	1.3	91.74
Tectona grandis	49	1.3	93.04
Carissa opaca	49	1.3	94.34
Nyctanthes arbor-tristis	39	1.05	95.39
Xeromphis spinosa	39	1.05	96.44
Flacourtia indica	30	0.78	97.22
Ziziphus oenoplia	30	0.78	98
Butea monosperma	10	0.25	98.25
Ziziphus xylopyra	10	0.25	98.5
Aegle marmelos	10	0.25	98.75
Grewia elastica	10	0.25	99
Shorea robusta	10	0.25	99.25
Gardenia turgida	10	0.25	99.5
Dalbergia sissoo	10	0.25	99.75
Murraya koenigii	10	0.25	100

No. of sampling points = 96

Table 4.21 Density (individuals/ha), percentage and cumulative percentage (Cum. %) of shrubs in plantations.

Plant species	Density	%	Cum. %
Lantana camara	1510	48.43	48.43
Adhatoda zeylanica	574	18.41	66.84
Helicteres isora	294	9.41	76.25
Mallotus philippensis	247	7.92	84.17
Holarrhena pubescens	172	5.52	89.69
Millettia extensa	51	1.64	91.33
Carissa opaca	42	1.35	92.68
Tectona grandis	36	1.15	93.83
Ehretia laevis	33	1.06	94.89
Miliusa velutina	27	0.87	95.76
Xeromphis spinosa	27	0.87	96.63
Ziziphus oenoplia	21	0.67	97.30
Cassia fistula	15	0.48	97.78
Murraya koenigii	15	0.48	98.26
Lagerstroemia parviflora	9	0.29	98.55
Casearia elliptica	9	0.29	98.84
Ziziphus xylopyra	9	0.29	99.13
Naringi crenulata	9	0.29	99.42
Aegle marmelos	6	0.19	99.61
Butea monosperma	6	0.19	99.80
Gardenia turgida	3	0.1	99.90
Kydia calycina	3	0.1	100

No. of sampling points = 262,

Table 4.22 Density (individuals/ha), percentage and cumulative percentage (Cum. %) of shrubs in Sal mixed forest on hills.

Plant species	Density	%	Cum. %
Mallotus philippensis	367	20.23	20.23
Carissa opaca	214	11.80	32.03
Adhatoda zeylanica	187	10.30	42.33
Holarrhena pubescens	165	9.10	51.43
Ehretia laevis	129	7.11	58.54
Lantana camara	112	6.17	64.71
Woodfordia fruiticosa	105	5.79	70.50
Xeromphis spinosa	102	5.62	76.12
Helicteres isora	97	5.35	81.47
Ziziphus xylopyra	92	5.07	86.54
Cassia fistula	58	3.20	89.74
Nyctanthes arbor-tristis	41	2.26	92.00
Gardenia turgida	41	2.26	94.26
Flacourtia indica	27	1.49	95.75
Ziziphus Oenoplia	22	1.21	96.96
Dendrocalamus strictus	15	0.83	97.79
Bauhinia malabarica	12	0.66	98.45
Dalbergia sissoo	10	0.55	99.00
Lagerstroemia parviflora	5	0.28	99.28
Naringi crenulata	5	0.28	99.56
Acacia catechu	2	0.11	99.67
Pinus roxburghii	2	0.11	99.78
Grewia elastica	2	0.11	99.89
Butea monosperma	2	0.11	100

No. of sampling points = 236

Table 4.23 Density (individuals/ha), percentage and cumulative percentage (Cum. %) of shrubs in Sal forest on hills.

Plant species	Density	%	Cum. %
Mallotus philippensis	684	34.39	34.39
Carissa opaca	233	11.71	46.10
Ehretia laevis	155	7.79	53.89
Adhatoda zeylanica	155	7.79	61.68
Holarrhena pubescens	148	7.44	69.12
Ziziphus xylopyra	117	5.88	75.00
Cassia fistula	93	4.68	79.68
Gardenia turgida	93	4.68	84.36
Lantana camara	78	3.92	88.28
Nyctanthes arbor-tristis	78	3.92	92.20
Xeromphis spinosa	62	3.12	95.32
Flacourtia indica	31	1.56	96.88
Helicteres isora	31	1.56	98.44
Woodfordia fruiticosa	23	1.16	99.60
Lagerstroemia parviflora	8	0.4	100

No. of sampling points = 77

Table 4.24 Density (individuals/ha), percentage and cumulative percentage (Cum. %) of shrubs in mixed forest on hills.

Plant species	Density	%	Cum. %
Adhatoda zeylanica	208	12.14	12.14
Helicteres isora	199	11.62	23.76
Carissa opaca	198	11.56	35.32
Mallotus philippensis	193	11.27	46.59
Holarrhena pubescens	174	10.16	56.75
Nyctanthes arbor-tristis	136	7.94	64.69
Ehretia laevis	108	6.30	70.99
Lantana camara	100	5.84	76.83
Ziziphus Oenoplia	57	3.33	80.16
Woodfordia fruiticosa	56	3.27	83.43
Ziziphus xylopyra	52	3.04	86.47
Cassia fistula	43	2.51	88.98
Flacourtia indica	39	2.28	91.26
Dendrocalamus strictus	34	1.98	93.24
Gardenia turgida	26	1.52	94.76
Xeromphis spinosa	23	1.34	96.10
Bauhinia purpurea	7	0.41	96.51
Naringi crenulata	7	0.41	96.92
Lagerstroemia parviflora	6	0.35	97.27
Murraya koenigii	6	0.35	97.62
Aegle marmelos	6	0.35	97.97
Miliusa velutina	5	0.29	98.26
Bauhinia malabarica	5	0.29	98.55
Acacia catechu	4	0.23	98.78

Ougeinia oogeinsis	3	0.18	98.96
Grewia hainesiana	3	0.18	99.14
Pinus roxburghii	2	0.11	99.25
Albizia procera	2	0.11	99.36
Kydia calycina	2	0.11	99.47
Dalbergia sissoo	2	0.11	99.58
Cordia dichotoma	1	0.06	99.64
Ziziphus mauritiana	1	0.06	99.70
Holoptelea integrifolia	1	0.06	99.76
Butea monosperma	1	0.06	99.82
Grewia elastica	1	0.06	99.88
Emblica officinalis	1	0.06	99.94
Firmiana fulgens	1	0.06	100

No. of sampling points = 548

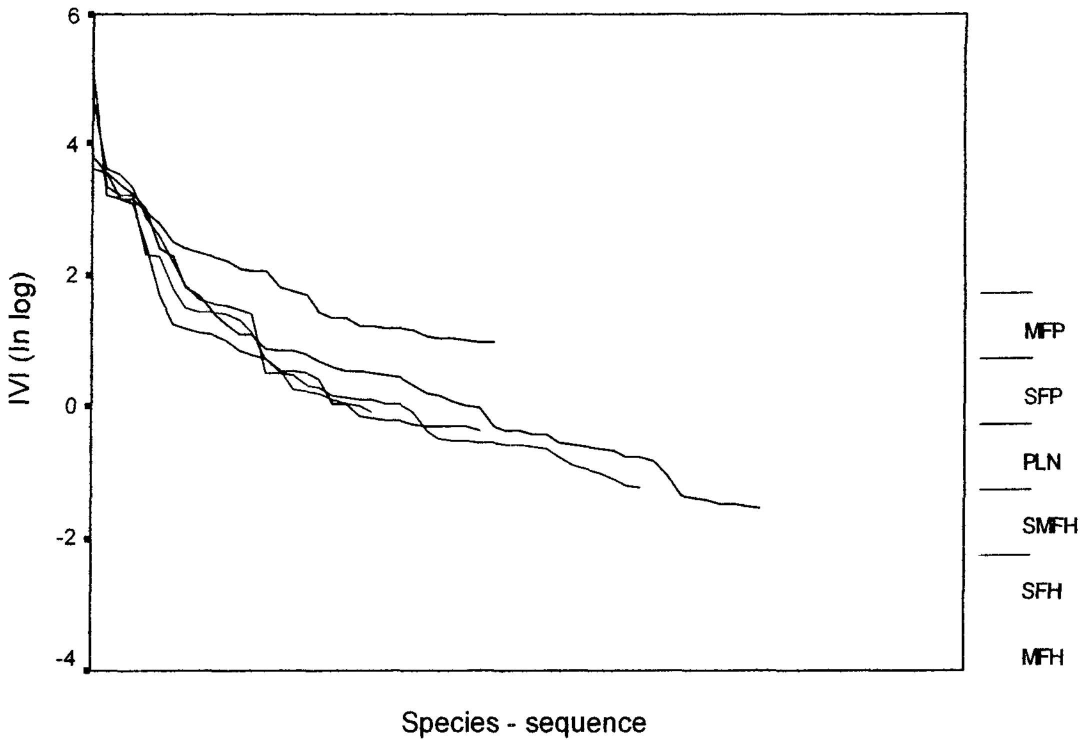


Fig. 4.4 Dominance Diversity Curve for tree species in different. forest types of Rajaji.

Chapter 5: Ranging and habitat utilization patterns

5.1 Introduction

The elephant population of the Rajaji National Park used to seasonally move between Rajaji-Motichur unit (western Rajaji N.P.) and the former Chilla Wildlife Sanctuary (eastern Rajaji N.P.) across the River Ganges. However, due to construction of a hydro-electric power generation station accompanying a 12 km long canal along the Ganges in Chilla WLS, establishment of an army ammunition depot, cultivation and expansion of township between western and eastern Rajaji NP (Fig. 2.1 in Chapter 2) the seasonal movements of elephant between the two units have more or less stopped. Some conservationists were of the opinion that elephants have completely stopped moving between the two seasonal ranges and the Rajaji population has been divided into two sub units, while others were of the opinion that the continuity is still maintained and at least few individuals still move between Rajaji-Motichur and Chilla WLS.

In a fragmented habitat like Rajaji National Park where developmental activities have nearly blocked the traditional movement routes of elephants between the two portions of the park, it is expected that a study on the ranging and habitat utilization pattern would help in assessing the constraints faced by the elephant populations in response to the altered habitat conditions. This in turn would also help in designing a conservation and management strategy for long-term wellbeing and survival of the elephant population in the Rajaji National Park.

In this chapter, I have examined the above mentioned issues along with the ecological explanation on the ranging and habitat utilization patterns of elephants in the Rajaji National Park.

5.2 Methodology

The studies on ranging and habitat utilization patterns of elephants in Rajaji National Park (Rajaji NP) were carried out by fixing radio-collars on two solitary adult males and two adult females in different groups. Elephants were immobilized by injecting required dosages (3 to 3.5 ml) of M-99 using "Disinject Dart Gun". Once an elephant was fully immobilized, a radio transmitter supplied by the "Wildlife Material Inc" USA was fixed around the neck. Due care was taken to have the transmitter with the exposed antenna on the dorsal side of the neck facilitating barrier free transmission of signal as well as recharging of batteries through solar radiations. After fitting a radio-collar, required amount of Revivon M-50 (antidote to M-99) was administered intravenously through a blood vessel in the ear. This revived the elephant from immobilized state with in a short period of 5 to 10 minutes. However, each elephant took nearly one hour to completely ward off the effect of the drug and resume normal activity.

5.2.1 Data collection

A TRX 12 radio-receiver with headphones and a hand held 3 element Yagi antenna were used for tracking the radio-collared elephants. Tracking of each radio-collared elephant was done and attempts were made to reach up to a place from where the elephant could be seen. A safe distance of about 50 to 100 m was maintained and due care was taken not to disturb the elephant so that normal activity is not hampered. Once the initial eye contact with the radio-collared elephant was established, its location was fixed on a 1: 50,000 scale topographic map of the Survey of India. For marking the elephant location, one km^2 grid was laid on the topographic map and the location of a grid on the map was identified in the field through the land marks and topographic features such as valleys, river/rivulets and ridge etc. Each location of elephant was then judged in relation to the grid and marked. For recording coordinates of elephant location another grid of 2 mm on a transparent sheet was overlaid on 1 km^2 grid to record animal location correct to a 100 m. Fig. 5.1 illustrates the method used for recording the coordinates of elephant locations. Apart from the radio-collared individuals, the locations of other elephants were also recorded in a similar manner. A systematic monthly search for elephants was also carried out from one end of the intensive study area to another in order to understand the distribution pattern. This normally took about a weak time. During each search, whenever a group or a solitary individual was sighted the location was marked on the map. Simultaneously, data on habitat parameters, such as topography, vegetation type etc were recorded at the site of elephant location. Two males were radio-collared in Rajaji Wildlife Sanctuary (Rajaji WLS) one each in 1986 (MR1) and another in 1987 (MR2). Two females (RFG in Rajaji WLS and CFG in Chilla WLS) in different groups were also radio-collared in 1988. All four elephants were tracked on foot on almost daily basis and whenever the initial eye contact with the collared elephant was established, its location was recorded only once on any day. Only day time sightings were recorded.

5.2.2 Data analysis

The home rages of radio-collared elephants were calculated and mapped, using coordinates of elephant locations through Harmonic Mean Transformation method, as described by Dixon and Chapman (1980). The computer programme McPaal was used for this purpose. Harmonic Mean Transformation is a method in which a harmonic mean minimum distance in respect to each location is calculated as a central tendency and a point is generated. This point is the inverse of first aerial movement and the line joining these points is called isopleth. The isopleths based on 90% sighting locations were generated so as to exclude single or few locations, which were mainly outliers from main activity area of the animal. The inclusion of such locations, which are due to erratic wandering, may over estimate home range size as it also includes areas occasionally visited by the animal.

The data on habitat utilization was analyzed using availability and utilization proportions. A vegetation map prepared by the Indian Institute of Remote Sensing, Dehradun was used to calculate availability proportions of different vegetation types in the study area as well as within the home range areas. The utilization proportions of various habitat types were calculated from the field data collected on the type of vegetation along with the location of animal. These proportions were used to construct 95% Bonferroni confidence intervals following Byers *et al.* (1984).

5.3 Results

A total of 721 locations of elephants were recorded during the study period. There were 253 locations of MR1, 179 locations of MR2, 146 and 143 locations of RFG and CFG respectively. The analysis of the data on home range size revealed that the there were marked differences in the annual home ranges among the radio-collared males and females. The annual home range of MR1 was 150 km^2 (Fig. 5.2) while the annual home range of another male (MR2) was about three times larger (451 km^2, Fig. 5.3) as compared to MR1. Similarly, the annual home range of RFG was 78 km^2 while it was only 12 km^2 in case of CFG (Fig. 5.4 & 5.5). The information about the annual and seasonal home range size of all the four collared elephants is provided in Table 5.1.

5.3.1 Seasonal movements and ranging pattern of a tusker (MR1)

The home range area occupied by MR1 was maximum during winter (91 km^2) as compared to summer and monsoon. The central portion of the Rajaji WLS around Dholkhund was observed to be mostly occupied and the elephant remained in this area for about three months (November to January). From February until the end of the winter in March, the elephant kept moving and utilizing the area between the northern boundary and central portion of the Rajaji WLS. The distribution of elephant locations indicate that the area within the range was more or less evenly used. However, a small area between the Dholkhund and Mohund appeared to have been used less as evident from the lower number of locations there (Fig. 5.6). At two occasions the elephant had moved to the Motichur WLS Sanctuary but returned the next day to Rajaji WLS.

The elephant ranged over an area of 66 km^2 during summer and utilized two distinct areas; one at the northern boundary of the Rajaji WLS and another in Beribara area. Both these areas had permanent water sources and most locations were around them. The movements of the elephant between mid March and April were largely restricted at the northern boundary. On the 4th May MR1 moved to its another summer locus in Beribara area and remained there till 31st May. On 1st of June the elephant moved again to Mohund area covering a distance of 14 km in a single day. The movements and the use of home range of this elephant appeared to be non uniform as indicated by cluster of locations in some area and none or few in other areas (Fig. 5.7).

The home range area of MR1 during monsoon was 71 km^2 and it utilized a considerable portion of southern part of the Rajaji WLS. The elephant was also reported to have moved out side the boundary of the Rajaji WLS and raided crops. The even distribution of locations within the range suggests a uniform pattern of range use. The movements within the range were restricted between Beribara and Ranipur areas of the sanctuary during July and August, it moved northward during September and occupied the area between Beribara and Dholkhund for rest of the monsoon season (Fig. 5.8).

5.3.2 Seasonal movements and ranging pattern of a Makna (MR2)

The MR 2 showed different pattern of movements and ranging as compared to the MR1. The elephant was captured and radio-collared in Rajaji WLS, however, it had extensively ranged over a larger area of all three sanctuaries. The winter range of MR2 was 250 km^2 and had three different foci; two were in the Rajaji WLS and one was in Chilla WLS. However a considerably higher number of locations (N=40) were recorded in the Chilla compared to 24 locations recorded in Rajaji WLS (Fig. 5.9). The elephant moved from the Rajaji WLS to the Chilla WLS without utilizing the area of Motichur WLS in between.

The elephant had more or less similar home range size during summer and it was 234 km^2. However, proportionately higher number of locations were recorded in the Rajaji WLS as compared to Chilla WLS (N= 12). There were 13 locations in the Motichur WLS as well. The distribution of locations was not uniform indicating uneven usage of the range area (Fig. 5.10). The elephant during summer regularly moved between the three sanctuaries after a gap of 15 to 20 days.

A reverse pattern of range use was observed during monsoon in which maximum number of locations were recorded in Chilla WLS (N= 45) and there were only 15 locations in the Rajaji WLS (Fig. 5.11). The range area occupied by MR2 during monsoon was minimum (229 km^2) of all seasons. During June the elephant remained in the Rajaji WLS and then moved to Chilla WLS and remained there for rest of the season.

5.3.3 Seasonal movements and ranging pattern of a female group (RFG)

The adult female (RGF) in a group was immobilized and radio-collared in the Rajaji WLS. The movements and range area of the group remained confined to the Rajaji WLS through out the study period. However, the range area kept shifting over the seasons within the Rajaji. During winter the group occupied central portion of the Rajaji WLS with a home range area of 69 km^2. The distribution of locations was uniform except a small cluster of locations at the southern end of the range (Fig. 5.12). During summer the group moved towards the northern boundary of the Rajaji WLS and remained there for whole of the season (Fig. 5.13). The summer range of the group was minimum (33 km^2) of all the seasons. During monsoon there was a slight shift in the range area towards the southern boundary (Fig. 5.14) and the group remained there for whole season. The range area during monsoon was 58 km^2.

5.3.4 Seasonal movements and ranging pattern of a female group (CFG)

A total of 143 locations of the group were recorded. This group remained confined to a limited area at the western boundary of Chilla WLS. There were little variations in the range size among different seasons. The range area occupied during winter was 11 km^2 while during summer and monsoon it was only 8 and 9 km^2 respectively. During winter the group mostly remained out side the boundary of the Rajaji NP and utilized an adjoining area in Chandi Forest Range (Chandi FR). There were only few locations across the boundary of the National Park in Chilla WLS (Fig. 5.15). In summer there was some shift in the range towards the Chilla WLS and almost equal number of locations were recorded inside and out side the boundary of the Chilla WLS (Fig. 5.16). The location of the range area remained more or less similar during monsoon as well (Fig. 5.17). The distribution of locations within the range area were uniform and compact indicating the compression of the home rage.

5.3.5 Seasonal distribution and movement patterns of elephants in Rajaji WLS

A total of 182 elephant locations were recorded and fixed on the map to understand the distribution pattern of elephants in the Rajaji WLS. There were 82 locations in winter and 51 and 54 locations in summer and monsoon respectively. The data on the distribution pattern of elephants revealed that the elephants occupied the central portion of the Rajaji WLS through out the year. However, there were differences in the pattern of occupancy of other areas of the sanctuary across various seasons. During winter, there was a high concentration of elephant location in Dholkhund area (Fig. 5.18), while during summer there were two foci where elephant locations were clumped; one around Dholkhund and another towards the southern side near Beribara area (Fig. 5.19). During monsoon, however, elephants were widely spread over the central and southern portion of the Rajaji WLS indicating a more uniform utilization of the area and its resources (Fig.5.20).

On the basis of frequency of encounters with elephants and recording the movements of some known groups within the Rajaji WLS, it was discernible that in general the elephants dispersed out of the Rajaji WLS during summer either to the adjoining Shivalik Forest Division or to Motichur WLS as few elephants were seen during summer in Rajaji WLS. The elephants started appearing in the Rajaji WLS again during monsoon and remained in the area until next summer. For instance, an elephant group was located and identified near the northern boundary of the Rajaji WLS on 9th March. The following night the group crossed over Delhi - Dehradun highway and entered in the Shivalik Forest Division. This group was followed for four days up to a distance of 30 km from the boundary of the Rajaji near a village Shahjahanpur. After few days the same group was reported to have moved up to a place called Timli on the bank of River Yamuna which is 60 km away from the boundary of Rajaji. Appearance of such a large group of elephant (about 24 individuals) in Timli was a rare event as it was not a frequent phenomenon at least in the recent past. This particular group was again observed in the Rajaji WLS during 1st week of October.

Another female group was identified on 2nd February and was observed in the Rajaji WLS on few occasions. This group was relocated in Motichur WLS during the 3rd weak of March and again it was seen in Beribara area during winter. However it could not be ascertained that for how long this group remained in Motichur WLS.

5.3.6 Seasonal habitat use pattern of elephants in Rajaji WLS

The study on habitat utilization pattern was carried out in the intensive study area. Five major habitat types found in the Rajaji were ranked in order of suitability for elephants from the feeding point of view. The ranking was based on the availability, distribution, density and diversity, of elephant food plant species (at tree and shrub level). Following are the ranks assigned to different habitat types:

i) Mixed forest on hills	Rank I
ii) Sal forest on hills	Rank II
iii) Mixed forest on plains	Rank III
iv) Sal mixed forest on plains	Rank IV
v) Plantations	Rank V

Analysis of the data on proportional availability and utilization of different habitat types with in home range area revealed that there were marked seasonal variations in the utilization of different habitat types. The elephants during winter utilized mixed forest on hills proportionately more than its availability, indicating preference. Sal forest on hills and mixed forest on plains were utilized in equal proportions than their availability while Sal mixed forest on plains and plantations were utilized in lower proportions than their availability, indicating no preference (Table 5.2).

The order of preference changed during the summer in which elephants preferred Sal forest on hills and plantations. Mixed forest on hills were least preferred while mixed forest on plains and Sal mixed forest on plains were used in proportion to their availability (Table 5.3).

During monsoon, mixed forest on hills was used more than the other habitat types. Mixed forest on plains and plantations were used in proportion to their availability while the Sal forest on hills and mixed forest on plains were used in lower proportions than their availability (Table 5.4).

5.4 Discussion

As per the theory of natural selection, activities of an animal should lead towards maximizing fitness in terms of reproductive success. Movement is one of the activities, which every animal performs in its life time. If an animal has to maximize its fitness than it can not afford to move aimlessly or in a haphazard manner. Therefore, animals mainly move in order to acquire food, water, shelter, cover, ward off predators and parasites and in search of mate etc (Pyke, 1983). However, once the aim of movement is decided then the next question is where to move in order to fulfill the objective. At least in case of social animals, after the birth, an individual establishes its own familiar area moving with the mother or other members of the group. Once an individual gets separated from the parent group, further extension of the familiar area would depend on either by exploring new areas (exploratory movements) or by social contacts with other groups or individuals. This familiar area can be regarded as animal home range and once it is established all movements within this area would then largely be calculated ones, in order to achieve fitness. Within this setting of natural selection if the aims of elephant movements are analysed than it is expected that movements would largely be in search and acquisition of food, water and mate. Predation risk to adult elephants is minimal, however, it is important from the point of view of young ones . Factors other than food may affect movements but only temporarily. Therefore, the daily or seasonal (short term) movements of elephants are mainly governed by the availability, quality and interspersion of food resources and water as has already been observed in both; the Asian and African elephants (Buechner *et al.*, 1963; McKay & Eisenberg, 1974; Western, 1975; Williamson, 1975; Rodgers & Elder, 1977; Leuthold & Sale, 1984; Sukumar, 1985; Easa, 1988).

An animal's continuous foraging in one patch does not appear to be a sound strategy because, according to Charnove (1976) such an animal would accumulate energy at decreasing rate. Considering that an animal also spends time in moving from one patch to another, it may be logically inferred that an animal continues to forage in a patch until its net rate of energy gain decreases to the overall rate of energy in the habitat (or forage optimally) and spends time to move to another patch with a view to increase the net rate of energy gain (Charnov, 1876). Pyke (1983) summed up to state that if an animal can do better elsewhere, it should leave otherwise it should stay where it is. Considering the high energy requirements of elephants it seems reasonable to accept that movements would largely be directed to optimize its food intake.

The perusal of movement pattern of elephants in the Rajaji WLS revealed that the movements and ranging pattern of all three radio-collared elephants; MR1, MR2 and RFG within the Rajaji WLS coincide with the general pattern of elephant distribution during different seasons (Fig. 5.6 to 5.14 and Fig. 5.18 to 5.20). Elephants were observed occupying southern part of the Rajaji WLS during monsoon and shifted towards the central part during winter. Presuming that elephants feed more frequently on the bamboo (*Dendrocalamus strictus*) during monsoon (Sale *et al.,* 1989), it is apparent that elephants were attracted towards the fresh growth of bamboo at the onset of monsoon which has comparatively higher density in the southern part of the Rajaji WLS. This view is further reinforced as elephants moved back to central part near Dholkhund when the bamboo leaves became coarse and less palatable.

In the foregoing discussion, the effects of various factors on the animals preference for certain parts of the large habitat and its tendency to remain more or less within it have been highlighted. However, it will be an over simplification to conclude that each factor acts independent of others. In fact, the species are surviving because of natural selection process by virtue of their inherent tendencies (which though not conscious, may be called innate wisdom) to adopt the strategies best suited in an ecological situation for their survival and wellbeing. Therefore giving precedence to one or the other factors may not be appropriate. It seems reasonable that a combination of factors such as quality, availability and interspersion of food resources, distribution pattern of the essential body requirements, process of finding a mate and economizing on energy appears to be strategic.

The preference to a particular habitat by elephants in the Rajaji WSL and the seasonal variations therein can better be explained if the above assertion is accepted.

The elephant were observed to prefer mixed forest on hills during winter and monsoon mainly due to availability of water within these habitats or at a convenient distance. However, with drying up of most water sources in summer, quality and quantity of food was compromised and elephants were seen utilizing otherwise comparatively low quality Sal forest on hills (rank II) and plantations (rank IV) where water continued to be available. The summer range of MRI, and RFG with two foci around water sources (Fig. 5.7 & 5.13), clumped distribution of elephants in summer (Fig. 5.19), movement of elephants out of Rajaji WLS and use of Motichur and Chilla WLS by MR2 along the Ganges during summer (Fig. 5.10) support that the availability of water was crucial factor and it influenced the movement and habitat use pattern during summer considerably. Apart from water availability of cover also played a role. During summer when temperature often reached around 40° C, cover was essential to avoid heat. Most of the hilly slopes have low density of trees with low canopy cover. Sal on the other hand grows on gentle slopes with relatively higher soil moisture and provide more canopy cover as compared to other vegetation types on hill slopes and hence was preferred during hot and dry summer. The use of Motichur forest during summer by MR2 appears to be a part of the same strategy. The slopes in Motichur WLS are gentle and support growth of Sal. About 70% of the area under Motichur WLS has Sal forest and MR2 was observed using part of it only during summer.

The differences in the home range areas in different habitat types have been observed in both; the Asian and the African elephants. For instance, Leuthold and Sale (1973) found that mean home range size varied between 350 and 1580 km^2 in Tsavo west and Tsavo east respectively and attributed that differences to the environmental conditions. Olivier (1978) found that the group home range size of elephants in Malayan primary forests was more than twice the size of home range in secondary forest and the differences were due to the differential availability of food plants. Sukumar (1985) reported the home range size of three bulls in south India between 170 and 320 km^2 while Sivaganesan and Bhushan (1986) estimated that the home range size in a sub-optimal habitat was 409 km^2. During the present study the home range varied between 12 and 451 km^2. The home range of male elephants were larger than that of the female groups.

Before attributing the reasons for differences in the home range sizes at various environmental conditions it is important to mention how home range size have been calculated since the range size and pattern both depends upon the methods employed in calculation of home range. In all the studies on the Asian elephants as mentioned above, the home range area was calculated using either minimum convex polygon or simply by joining the peripheral locations forming the range boundary. Both these methods generally overestimate the range size as they include areas less frequented or not at all visited by the animal. Moreover, the range size tends to increase with number of locations and to reach to an asymptote, more than 30 locations are required. The mean harmonic transformation method (HMM), as employed in calculation of range area during the present study does not get affected by the sample size (number of locations) and a sample size of even less than 30 can produce satisfactory results. The HMM measures the central tendency of animal activity area and therefore provides a more faithful representation of the home range size. Furthermore, the 90% isopleth excludes peripheral locations, which are far away from the activity centre(s). Considering this, it does not seem appropriate to compare home range size with other studies as mentioned above. However, of importance is the variation in the home range size within the same ecological area.

During the present study, marked variations were observed between the range size of males and female groups, individuals of the same sex and seasonal variation in the range size of same individual/ group.

Eisenberg (1981) noticed a larger home range area of female groups as compared to male elephant in Sri Lanka while Barnes (1982) observed that male African elephant traveled long distances in search of females in estrus during wet season. Sukumar (1985), on the other hand, did not notice much change in the ranging pattern of males and female groups. During the present study home range size of males were much larger than the female groups, which is contradictory to the findings of Eisenberg. Therefore, it is difficult to arrive at a firm conclusion regarding the variations in home range size between male and female groups. However, it is plausible to accept that male elephant can afford to move over larger area as no predation risk is involved and also the solitary male is not constrained to maintain cohesiveness of the group. The female groups normally accompanying juvenile are concerned with the safety of their offspring and would not unnecessarily expose their progeny to predation risk. Secondly, the presence of juveniles also restrict the movements of adult animals of the group and hence it is expected that the home range of female groups would be smaller than that of the males.

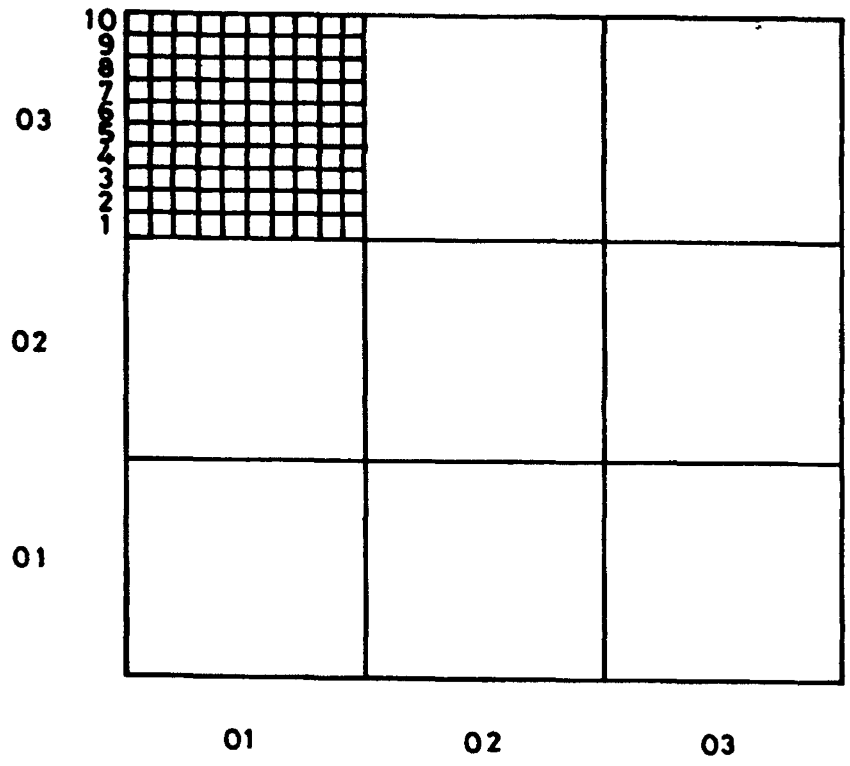
The difference between the range size of two female groups (RFG & CFG) can also be attributed to the presence of juveniles. The RFG had large calves in the group while the CFG was accompanying a small calf less of a year and hence its range was more or less restricted to a small portion at the boundary of Chilla WLS. The presence of this group close to the human habitation may also be a part of adaptive strategy to lower the predation risk.

The differences between the range sizes of male elephants during the present study are in conformity with the results as obtained by Sukumar (1985). At this stage, it is difficult to answer as to why different males show such large variations in ranging pattern within one ecological area. However, some preliminary conclusions can be drawn considering that the finding of mate is one of the major reasons for an adult male elephant to move over a large area in search of a female. However, the choice of mating rests with the females. According to weatherhead (1984), apart from other considerations like good genetic constitution, holding of good quality resources and ability to accord better protection etc, a female may choose to mate with a male having a particular phenotypic characteristic, which serves as a conventional attractant to the female, without any functional value. In case of elephants, it is likely that the good quality tusks serve as conventional attractant to the females and therefore the tusker male had higher chances of being chosen by the available females as compared to the tusk less male. It is for this reason that the range of Makna male was three times greater than that of the tusker. However, this cannot be treated, as conclusive and further long-term study is highly desirable to unfold the reasons of varying home range sizes among different males.

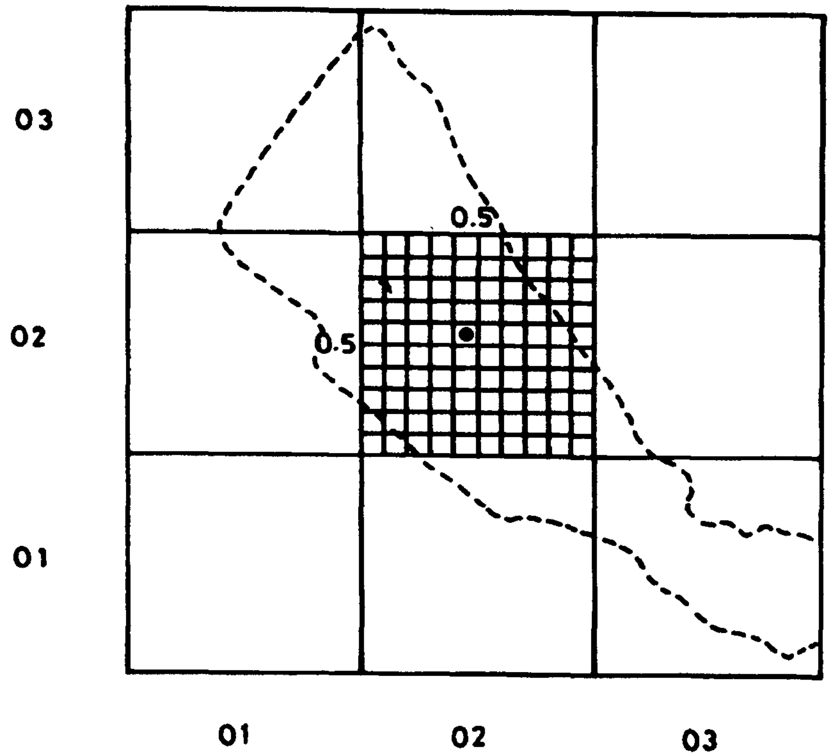
5.5 Summary and conclusions

The ranging pattern of elephants in the Rajaji indicated that there were marked variations in the home range sizes of male and female groups. The home ranges of males were larger than that of the females and the reasons attributed to this include; restricted movements of female groups due to the presence of juveniles, maintenance of cohesiveness among the members of the group, male's strategy to explore new areas and finding mates. The seasonal variation in range sizes and habitat use patterns were largely due to the differential availability of good quality forage among different habitat types when water was available at a convenient distance from the foraging sites. During summer, when most water bodies dried up, the elephants were observed compromising the quality of habitat they occupy over the availability of water. Female choice of mate may influence range size among males.

Apart from the above it is also conclusively established that the genetic continuity among the two sub groups of elephants inhabiting Rajaji-Motichur and Chilla units is maintained by occasional movements of solitary males and hence protection of corridor between the two units is of utmost important. However, the movement of female groups through the corridor was not evident. It is discernible from the movement pattern of elephants that the year round utilization of the resources of Rajaji WLS by the present population may not be sustainable and therefore part of the elephant population moves during summer to areas not frequented by elephants at least in the recent past.



Millimeter grid on 2 cm cell



Millimeter grid overlaid 2 cm grid cell on the map

Fig. 5.1 Process of recording coordinates of elephant locations.

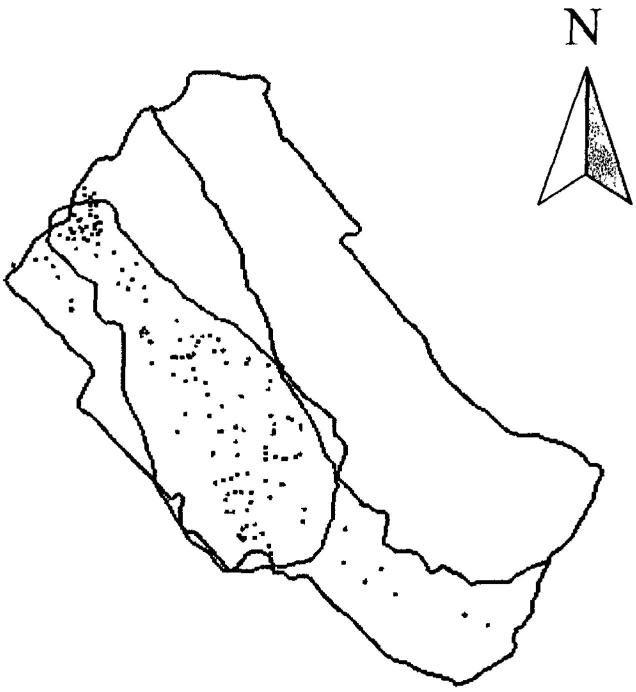


Fig. 5.2 Annual home range of a radio- collared tusker (MR1).

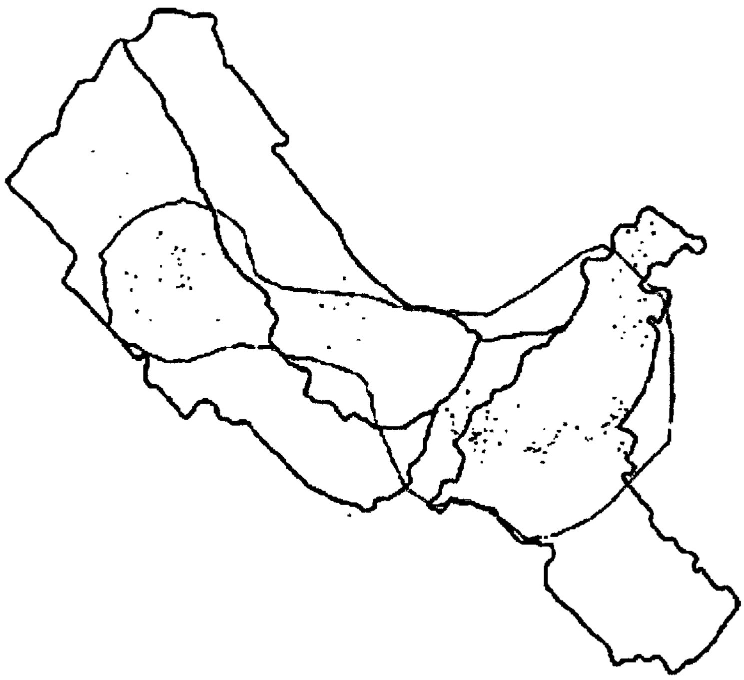


Fig. 5.3 Annual home range of a radio- collared Makna (MR2).

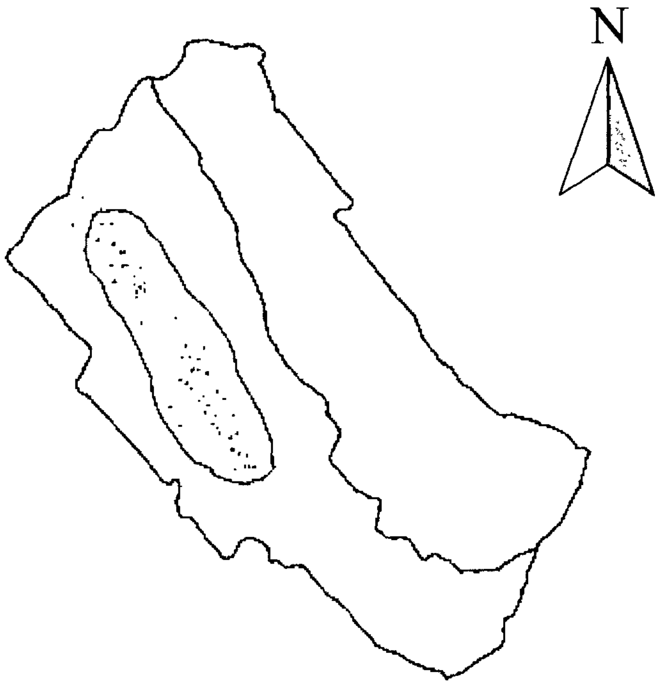


Fig. 5.4 Annual home range of a radio- collared female (RFG).

Fig. 5.5 Annual home range of a radio-collared female (CFG).

Table 5.1 Number of locations (N) and seasonal home range area (km^2) of four radio-collared elephants in Rajaji National Park.

Elephant codes	Winter home range		Summer home range		Monsoon home range		Annual home range	
	N	Area	N	Area	N	Area	N	Area
Adult male tusker (MR1)	89	90.56	97	66.39	67	71.10	253	150.88
Adult male Makna (MR1)	55	249.50	64	258.64	60	234.22	179	451.42
Adult female (RFG)	55	69.44	52	32.99	36	58.35	143	71.96
Adult female (CFG)	63	10.99	51	7.85	32	8.93	146	11.97

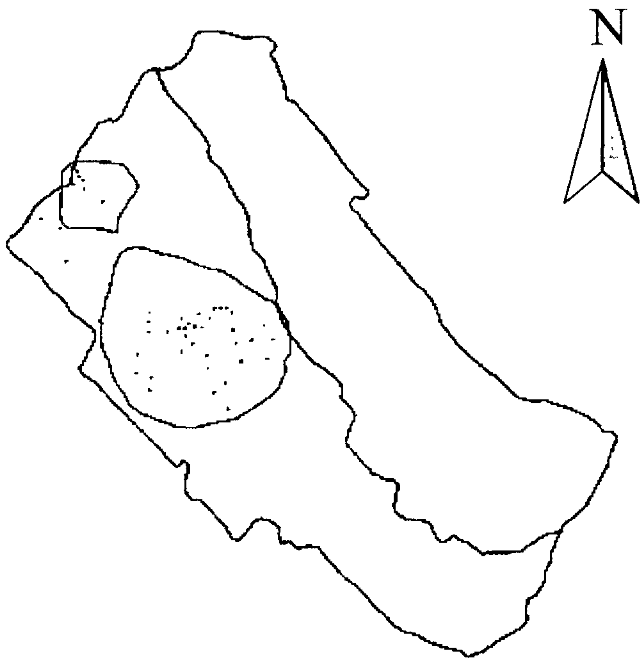


Fig. 5.6 Winter home range of a radio-collared tusker (MR1).

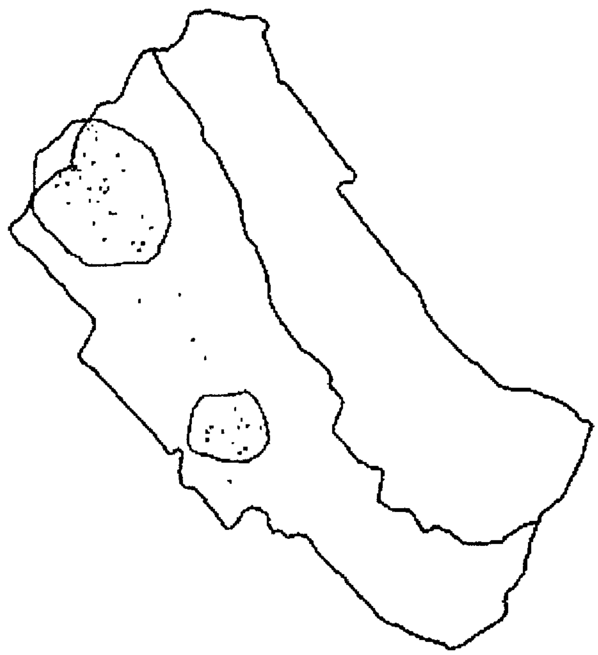


Fig. 5.7 Summer home range of a radio- collared tusker (MR1).

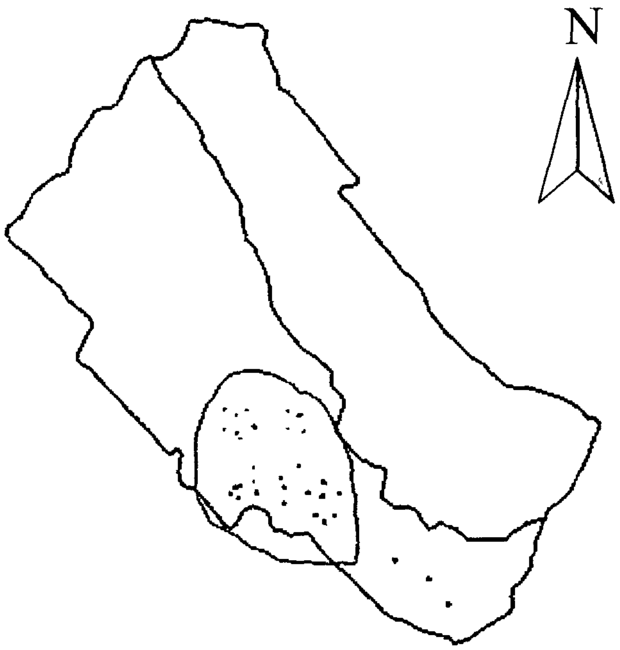


Fig. 5.8 Monsoon home range of a radio-collared tusker (MR1).

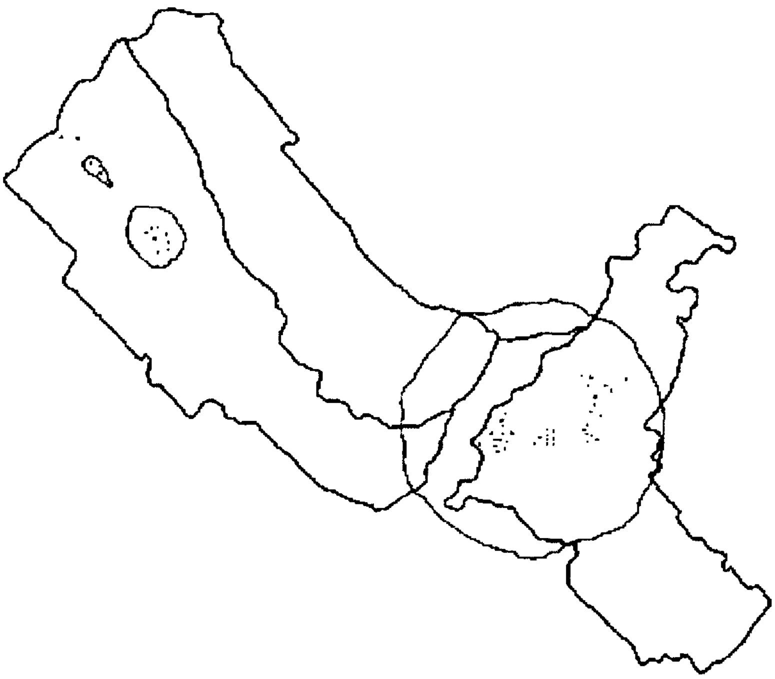


Fig. 5.9 Winter home range of a radio-collared Makna (MR2).

Fig. 5.10 Summer home range of a radio-collared Makna (MR2).

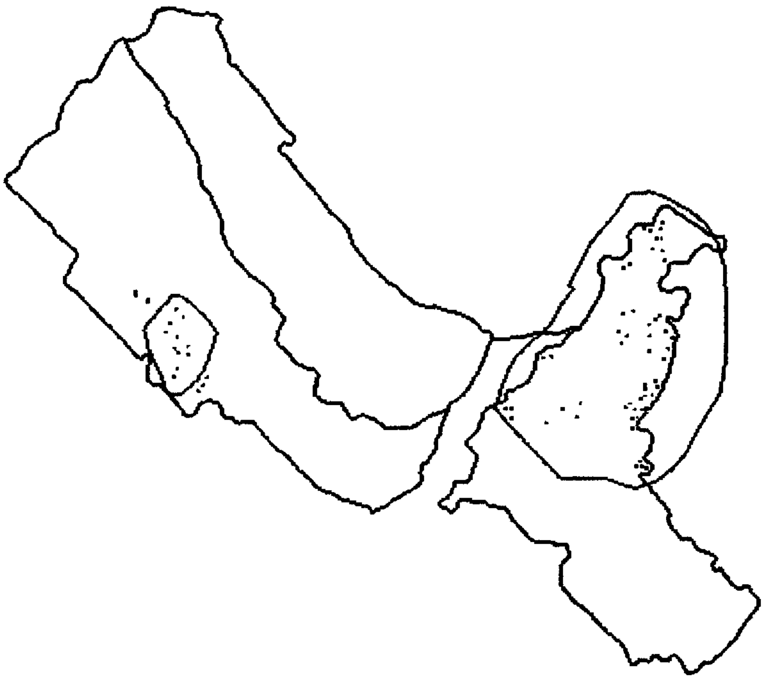


Fig. 5.11 Monsoon home range of a radio- collared Makna (MR2).

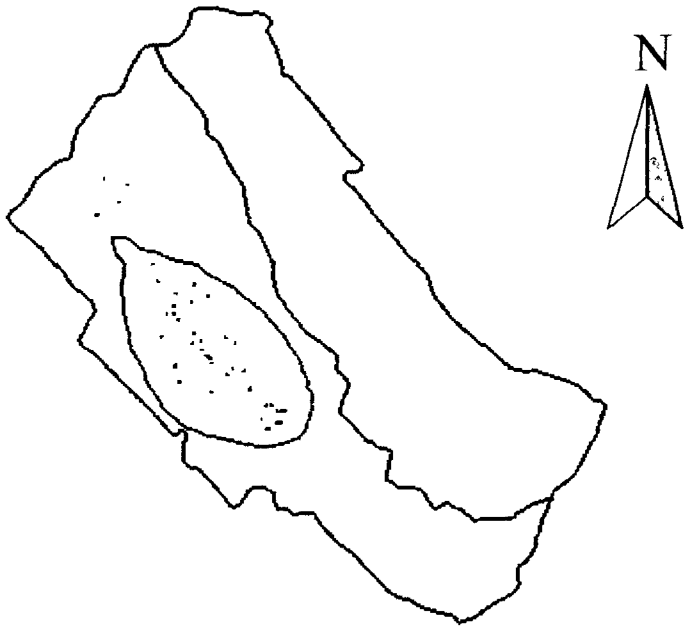


Fig. 5.12 Winter home range of a radio- collared female (RFG).

Fig. 5.13 Summer home range of a radio- collared female (RFG).

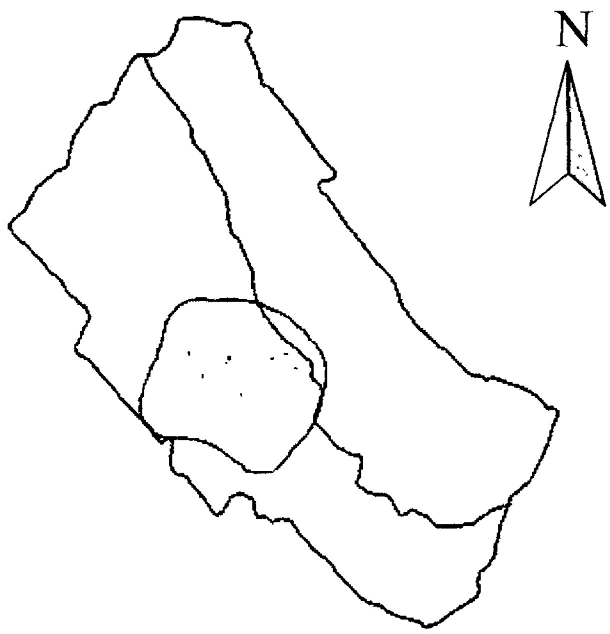


Fig. 5.14 Monsoon home range of a radio- collared female (RFG).

Fig. 5.15 Winter home range of a radio- collared female (CFG).

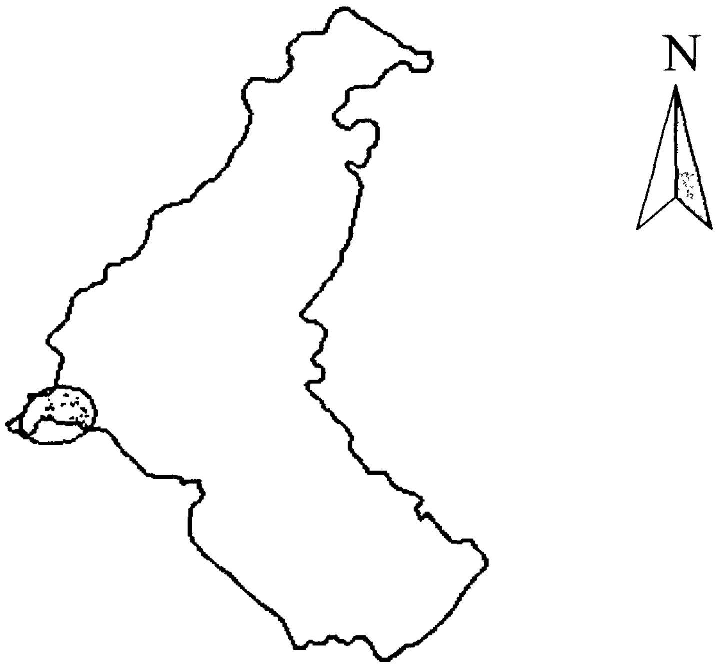


Fig. 5.16 Summer home range of a radio-collared female (CFG).

Fig. 5.17 Monsoon home range of a radio- collared female (CFG).

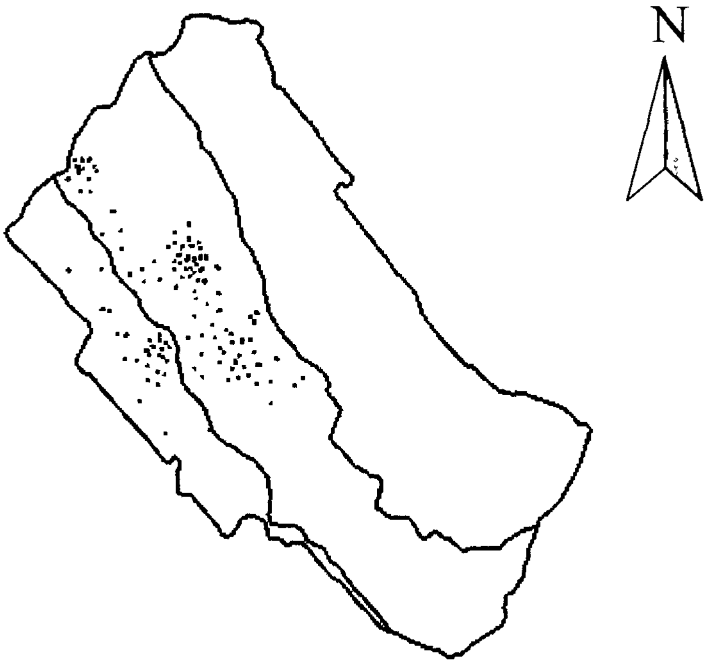


Fig. 5.18 Winter distribution of elephants in Rajaji.

Fig. 5.19 Summer distribution of elephants in Rajaji.

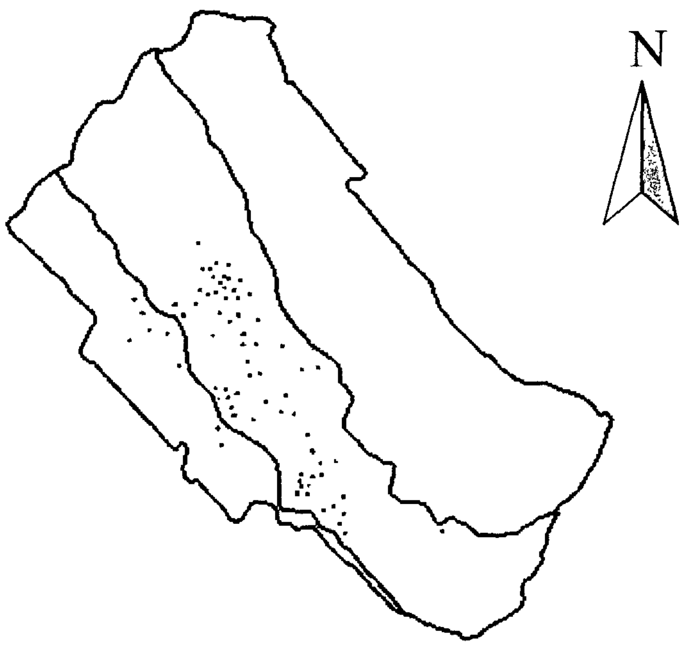


Fig. 5.20 Monsoon distribution of elephants in Rajaji.

Table 5.2 Proportional availability (P_{io}) and utilization (P_{ie}) of different habitat types by elephants during winter in Rajaji.

Habitat types	P_{io}	P_{ie}	95% confidence interval Lower Limit		Upper Limit	Significance level
Mixed forest on hills	0.4411	0.5852	0.5447	$\leq P1 \geq$	0.6257	+
Sal forest on hills	0.1663	0.1917	0.1593	$\leq P2 \geq$	0.2240	0
Mixed forest on plains	0.0953	0.0958	0.0716	$\leq P3 \geq$	0.1200	0
Sal mixed forest on plains	0.1906	0.0474	0.0299	$\leq P4 \geq$	0.0648	
Plantations	0.1064	0.0797	0.0574	$\leq P5 \geq$	0.1019	

+ = Utilized significantly more than availability
0 = Utilized in proportion to availability
- = Utilized significantly less than availability

Table 5.3 Proportional availability (P_{io}) and utilization (P_{ie}) of different habitat types by elephants during summer in Rajaji.

Habitat types	P_{io}	P_{ie}	95% confidence interval Lower Limit		Upper Limit	Significance level
Mixed forest on hills	0.6036	0.0930	0.3456	$\leq P1 \geq$	0.4403	-
Sal forest on hills	0.1763	0.2950	0.2508	$\leq P2 \geq$	0.3391	+
Mixed forest on plains	0.1509	0.1470	0.1126	$\leq P3 \geq$	0.1813	0
Sal mixed forest on plains	0.0239	0.0160	0.0038	$\leq P4 \geq$	0.0281	0
Plantations	0.0451	0.1490	0.1144	$\leq P5 \geq$	0.1835	+

+ = Utilized significantly more than availability
0 = Utilized in proportion to availability
- = Utilized significantly less than availability

Table 5.4 Proportional availability (P_{io}) and utilization (P_{ie}) of different habitat types by elephants during monsoon in Rajaji.

Habitat types	P_{io}	P_{ie}	95% confidence interval Lower Limit		Upper Limit	Significance level
Mixed forest on hills	0.6345	0.6760	0.6383	$\leq P1 \geq$	0.7136	+
Sal forest on hills	0.0419	0.0210	0.0094	$\leq P2 \geq$	0.0325	-
Mixed forest on plains	0.1549	0.1520	0.1230	$\leq P3 \geq$	0.1809	0
Sal mixed forest on plains	0.0419	0.0210	0.0094	$\leq P4 \geq$	0.0325	-
Plantations	0.1267	0.1300	0.1029	$\leq P5 \geq$	0.1570	0

+ = Utilized significantly more than availability
0 = Utilized in proportion to availability
- = Utilized significantly less than availability

Chapter 6: Feeding ecology and its impact on vegetation

6.1 Introduction

The daily food intake of the Asian elephant is between 82 and 150 kg (MacKay, 1973; Vancuylenberg, 1977). It is expected that feeding on vegetation in such large quantities may have profound influence on composition and dynamics. In Africa, the interaction between elephants and vegetation is one of the main causes for concern over other ecological conditions (de Jonge, 1986). In Africa, much attention has been paid during the last several decades to the problems related to feeding and its impact on vegetation, which has a strong bearing on ranging, and movement patterns of the species. Some of the studies carried out on this aspect includes, Glover (1968), Bax and Sheldrick (1963), Laws (1970), Penzhorn *et al.* (1974), Anderson and walker (1974), Kortlandt (1976), Jachmann and Bell (1985) and Guy (1989). However little attention has been paid to this important aspect of elephant ecology in Asia and few preliminary studies have so far been carried out (Vancuylenberg, 1977; Olivier, 1978; Ishwaran, 1983; Sukumar, 1985; Boumeester, 1986; Sivaganesan & Sathyanarayana, 1995).

Studies pertaining to aspects of feeding and its impact on the vegetation have not yet been attempted on the northwestern elephant population. In a situation like Rajaji National Park, where habitat destruction is taking place, seasonal movements between the traditional ranges have been nearly stopped and elephant population is surviving on limited resource base, it is important to understand the feeding impact on the vegetation. This will not only help in habitat manipulation (if required) but also important for management and conservation of elephants.

In this chapter, I have made efforts to describe the dietary spectrum of elephants, seasonal changes in the diet and factors responsible for variation between seasons. It also describes the food preference of elephants if any and impact of feeding on to the vegetation of the Rajaji WLS.

6.2 Methodology

Following methods were used to collect field data and its analysis on dietary spectrum, preference and feeding impact on vegetation:

6.2.1 Data collection

Elephant were followed during the daytime and direct observations were made on feeding individuals using *adlibitum* and focal animal sampling methods (Altman, 1974). Continuous observations for longer duration were not possible due to thick under story at several places, rugged terrain, and shy nature of elephants and personal security. At several places it proved impossible to identify plant species or plant parts eaten correctly even from a distance of 20 m. Indirect method (described in the following section) was however used for filling the gaps in required information collected by direct observations.

Three components of food consumed by the animals were recognized during the observations, each of which has been defined and elaborated as below:

i) Bark: bark peeled off and eaten either from main tree stem or from any other branch.

ii) Branches: terminal portion or any other portion of branch eaten with both; leaves and twigs.

iii) Leaves: when selectively eaten by discarding the twigs.

To assess the impact of elephant feeding on the mature trees (>30 cm GBH), ten belt transects (each 10 m wide) of varying lengths were systematically laid throughout the Rajaji WLS . Each damaged plant was identified as to species and its height and GBH were measured.

Damage to each plant was assessed and the nature and extent of damage was quantified under the following damage types and damage categories.

Type 1: Debarking : the removal of bark either from the main tree trunk or from any prominent branch.

Category I : Low damage; up to 30% of stem area debarked.

Category II: Moderate damage; up to 60% of stem area debarked.

Category III: Heavy damage ; more than 60% of stem area debarked.

Type 2: Crown breaking: Any damage to tree foliage.

Category I : Low damage; up to 30% of total crown damaged.

Category II: Moderate damage; up to 60% of total crown damaged.

Category III: Heavy damage; more than 60% of total crown damaged.

Type 3: Pushing over: Trees either uprooted or the main stem completely broken.

Type 4: Stem twisting: trees not completely uprooted or broken but only pushed and partly pulled down.

Category I : Pushed but survived.

Category II: Low chance of survival.

Category III: Completely dead.

The damage to the trees, which was less than one year old, was recorded.

6.2.2 Data analysis

The data on dietary spectrum was summarized and percentage of different plant species contributing to the diet of elephants was calculated for different seasons. Chi-square test was used to see the differences in the seasonal use of different plant parts eaten by the elephants. As no reliable and appropriate method has so far been evolved for precise quantitative measurement of browse availability and utilization; an arbitrary assessment was resorted to. Elephant feeding signs on trees, irrespective of the extent of the consumption, were regarded as indication of utilization. Such trees along 10 m wide belt transects were enumerated and densities and percentage of each tree species were found out. Relative availability of elephant food tree species were also determined in term of densities along the same transects. The data on availability and utilization were used to construct Bonferroni confidence intervals following Byers *et al.* (1984) in order to see the preference (if any) to a particular species.

6.3 Results

A total of 819 feeding observations were recorded during the study out of which there were 386, 208 and 225 records in winter, summer and monsoon respectively. A total 38 plant species belonging to 23 families were identified as elephant food species and out of these 33 species were directly observed being eaten.

6.3.1 Dietary spectrum of elephants in Rajaji

The analysis of the data suggested that grasses constitute only 4.9 percent of the total diet of elephants in the Rajaji suggesting that the bulk of elephant diet is browse. Seasonal differences in grass consumption were observed and proportionately higher consumption was recorded during monsoon as compared to winter and summer

(Table 6.1). However, the difference was not statistically significant (χ^2 = 2.27, d.f. = 2, P>0.05).

First ten species listed in Table 6.2 constitute the bulk (70 percent) of the elephant diet and were considered as major food species. All the major food plant species were found to be eaten throughout the year with the sole exception of *Kydia calycina*, which was not eaten during winter. *Mallotus philippensis* and *Ehretia laevis* were eaten more frequently in winter and summer as compared to monsoon. There were seasonal differences in utilization of different plant species. For instance, *Dendrocalamus strictus* and *Dalbergia sissoo* were eaten more during monsoon than in summer and winter while *M. philippensis* and *E. laevis* were eaten more frequently in winter and summer as compared to monsoon. Though *K. calycina* was not eaten during winter but constituted about six percent of the diet during monsoon. The species like *Lagerstroemia parviflora*, *Ficus rumphii* and *Albizia lebbeck* were not in the list of major food plant species but formed an important part of elephants' diet only during summer accounting for 5.1, 5.9 and 4.2 percent respectively. The information on plant species and their percentage in the diet of elephants during different seasons is provided in Table 6.2.

6.3.2 Proportion of plant parts in the diet

The analysis of data on plant portion consumed by the elephants revealed that bark was the major component of the diet constituting 62 percent. Other plant parts were consumed in lesser proportions; branches and leaves accounted for 19 and percent 14 percent of the diet respectively. The remaining 4 percent was grasses.

The proportion of plant parts eaten in each season are presented in Table 6.3. The Chi-square test showed that there were significant seasonal differences in the frequencies of bark eaten (χ^2 = 12.10, d.f. = 2, P <0.01) The highest utilization of bark was recorded during winter (65%) and lowest (37%) during summer. Branches were eaten more or less in equal proportions during winter and summer, while their proportion in the diet was relatively reduced during monsoon (19%). However the differences in utilization of branches during three seasons were not statistically significant ($\chi^2 = 2.3$, d.f. = 2, P>0.05). Similarly, there were seasonal differences in the consumption of leaves, which were consumed in higher proportion during summer (37%) as compared to monsoon (17%) and winter (7%). The differences in consumption of leaves between different seasons were significant ($\chi^2 = 15.23$, d.f. = 2, $P < 0.01$).

The proportions of plant parts of each species eaten by elephants are given in Table 6.4. Different plant parts of each food plant species were observed in varying proportions. For instance, the bark of *Acacia catechu, Ehretia laevis, Bombax ceiba* etc was frequently eaten while, the branches and leaves of *Dendrocalamus strictus, Albizia lebbeck and Grewia optiva* etc were consumed more. Moreover, it was also observed that the consumption of specific plant part was not indiscriminate. The tough bark from the stem or from any of the prominent branches of some species (e.g. *Acacia catechu, Dalbergia sissoo* and *Shorea robusta*) were eaten but in case of other tree species like *Aegle marmelos, Bauhinia malabarica, Ziziphus xylopyra* and *Mallotus philippensis*, bark from smaller branches (as thin as 2 cm in girth) was consumed.

6.3.3 Feeding impact on vegetation

A total of 27 food tree species identified, had a density of 216 trees /ha. The density of damaged trees was 12 trees/ha. Thus, the total damage to the food trees was 5.5 percent in one-year time.

6.3.3.1 Type and extent of damage

The maximum damage to tree species was recorded by pushing over and it was 66 percent. The damage caused by crown breaking, stem twisting and debarking was recorded as 17. 5%, 9,6% and 6.4 % respectively (Fig. 6.1).

Most of the pushed over trees were found dead. However, several trees damaged in this manner a few days before the observation were still green but appeared destined to die in due course. Even such trees were considered dead and their total was 521.

The crown breaking is not a serious type of damage, as it does not lead to mortality of the trees but retards growth. Of all the trees found damaged by "crown breaking" about 47% belonged to the first category of damage (i.e. low damage) while 38 % were moderately damaged and 14% were recorded in the category of high damage (Fig 6.2).

Stem twisting by itself does not cause instant mortality to the trees because root connections are maintained. However, further damage to such trees by other agencies leads to mortality. During the present study convincing evidences of fire, browsing by other herbivores and wood cutting by people were observed. Under such circumstances it was not possible to conclude which of the tree had died or were destined to die as a result of stem twisting by elephants or damage inflicted by other agencies after stem twisting. Of the total 72 trees damaged by stem twisting, 8.8% trees were found dead while 63.3% were surviving and 27.9% trees were recorded under the category in which chances of survival were low (Fig. 6.3)

The maximum percentage of trees (55.5%) damaged by debarking were found in the category of low damage. It was followed by comparatively lower percentage (27.7%) belonging to high damage category while the minimum percentage (16.6%) belonged to the moderate damage category (Fig. 6.4).

6.3.3.2 Damage to the tree species

Six severely damaged food tree species were identified on the basis of their relative availability and their proportional damage. The highest damage was recorded on *Mallotus philippensis* followed by *Aegle marmelos, Bauhinia, malabarica* and *Garuga pinnata* (Table 6.5).

Distinction has to be made between the extent of damage (quantitative severity) and the type of damage (qualitative manner) caused to the trees by the elephants. Three different parameters were used for the assessment of damage; a) the number of trees of each species found damaged expressed in terms of percentage, b) the extent or severity of damage to trees of different species expressed in terms of three categories and c) overall damage calculated by taking both the above parameters together.

Certain tree species were found frequently (numerically) damaged but without much sever damage. Certain other tree species on the other hand were found far less frequently damaged but the extent of damage to each was considerable. It is difficult to take into account these two variables, nevertheless, it seems necessary to keep in view of both; type and extent of damage in order to arrive at a comparative conclusion in regard to damage. Table 6.5 reveals that *Albizia lebbeck* and *Ficus benghalensis* have been found to suffer 7.9% and 9% of damage respectively, still these species on the whole have not been considered severely damaged. In case of *Ficus,* little damage was observed by crown breaking and debarking on each individual tree but a much higher percentage of these trees were found damaged. In case of *Albizia,* crown breaking and stem twisting was found to be common in proportion to their availability. However, in both the cases, the frequency of damage was higher but the extent of damage was not severe and hence both the species were not included in the list of severely damaged tree species.

6.3.3.3 Damage and tree GBH

The percentages of four damage types among ten girth classes are depicted in Fig 6.5. The examination of data revealed that the trees in smaller girth classes were more vulnerable to damage as compared to the trees in higher girth classes. The maximum damage in all categories of damage types were between the girth classes 30 and 90 cm except debarking where comparatively higher damage was recorded in GBH categories between 51 and 90 cm (Fig. 6.6 to 6.9).

6.3.4 Food preference

The principal foods of an animal are those, which it eats in large quantities. These foods, however, may not be preferred. The preferred food species are those, which are proportionately more frequent in the diet than their availability in the environment. Therefore, to understand the elephant preference to a particular species, Bonferroni confidence intervals were constructed which take into consideration the proportions of availability and utilization. The Bonferroni confidence intervals were constructed only for tree and woody climber species, as it was difficult to record accurately the consumption of grasses and herbaceous plants through indirect method. Secondly, the assessment of availability of grasses and other herbaceous plants is time consuming and to some extent difficult. Moreover, the bulk of elephant diet in Rajaji comprised of woody vegetation.

The analysis of availability and utilization data showed that out of 27 plant species recorded being eaten by the elephants only four species were found being consumed in greater proportion than their availability, 14 species were consumed in proportion to their availability while seven species were consumed less than their availability in the Rajaji. The species preferred by elephants were *Mallotus philippensis, Aegle marmelos, Bauhinia malabarica* and *Stereospermum suaveolens* (Table 6.6). About

20% of elephant diet in the Rajaji was composed of *Mallotus philippensis* and it was also found to be preferred. However, other species such as *Ehretia laevis* (8.6%), *Grewia elastica* (5.7%), *Dalbergia sissoo* (9.8%), *Kydia calycina* (7.8) and *Acacia catechu* (3.3%) contribute considerable proportions in the diet of elephants even than their utilization was in proportion to their availability indicating no preference. Contrary to that, species such as *Aegle marmelos* (1.8%), *Bauhinia malabarica* (1.3%) and *Stereospermum suaveolens* (0.4%) contribute only in fractions in the diet yet these species were consumed more than their proportion, indicating preference.

6.4 Discussion

Studies on both the African and the Asian elephants have revealed that grasses form major component of elephant diet. Buss (1961) after examining 71 stomach contents found that the proportion of grasses was about 80% in the diet. Bax and Sheldrick (1963) stated that grasses, creepers and herbs form the bulk of elephant diet in Tsavo east. Wing and Buss (1970) estimated about 92% grass contents in the feaces of elephants. Laws *et al.* (1975) observed the grass proportions in the diet of elephants were more or less similar to those estimated by Wing and Buss. In Sri Lanka McKay (1973) observed elephants feeding intensively on grasses while Olivier (1978) found fairly reduced proportions of grasses in the diet of elephants in Malayan rain forests. This low intake (33%) of grasses in Malayan rain forests was related to the availability of grasses there. The positive relationship between the availability of grasses and their intake by elephants were best illustrated by Sukumar (1985). He found higher proportions of grasses in the diet, in grass dominated habitat. A moderate proportion of grass component in mixed habitat and least proportions of grass in the diet in browse dominated habitat. The results of the present study regarding the intake of grasses by elephants are not comparable to other studies. If the availability of grasses in the habitat is considered as the governing factor for proportion of grasses in the diet of elephants, then grass contents in the diet of Rajaji elephants are expected to be low too, as the availability of grasses in Rajaji is lower than all the above mentioned studies. However, the Malayan rain forests are an exception to this where availability is expected to be lower than Rajaji, yet the grasses constitute 33% of elephant diet, which is about six times higher than Rajaji. This reversal of positive correlation between availability and consumption of grasses in the Malayan rain forests refutes the above hypothesis. This leads to conclusion that availability may not be the only reason for varying proportion of grasses in the diet of elephants among different habitats. In Rajaji, it has been observed that such low proportions of grasses in elephant diet were mainly due to the distribution of grasses. As such no grasslands exist in the Rajaji. Only small patches of grass are found on rugged hill slopes and probably elephants will have to spend considerable energy in reaching such grass patches than they may gain by feeding on grasses there. The nutritional requirements of elephants in Rajaji are presumably met by the browse, which is quite easily available and this could also be a possible reason of low grass intake. This however, requires an in depth study on elephants' physiological demand and chemical composition of plant species in order to arrive on a firm conclusion.

The seasonal differences in grass intake by elephants have already been documented for the African as well as the Asian elephants. For instance, Field (1971) found that the proportion of grasses in the diet of the African elephants reaches to a maximum of 90% during the wet season. Wyatt and Eltringham (1974) and Barnes (1982) also arrived at similar conclusions. Among the Asian elephants (Sukumar, 1985) observed that elephants in south India spend more time feeding on grasses during wet season as compared to dry season. The results of the present study also indicate that grass consumption increases during monsoon and reaches to its minimum during summer. Comparatively higher grass intake during monsoon can be attributed to its easy availability, high palatability and comparatively higher nutritional values.

A review of literature indicates that elephant populations inhabiting diverse climatic conditions and vegetation types survive on a variety of food plant species. Studies on the African elephants have shown that the food spectrum varies from one habitat to another. Field and Buss (1976) have listed 59 plant species as elephant food in East African Kidepo valley. Guy (1976) included 133 plant species in Sengwa area Rhodesia, while 134 plant species have been reported eaten by elephants in Lake Manyara National Park (Douglas-Hamilton, 1972).

Studies on the Asian elephants have also shown differences in the food spectrum in varied climatic regions. McKay (1973) found that elephant diet in Gal Oya National Park includes 89 plant species while in Malayan rain forests (Olivier, 1978) reported 390 food plant species. In the Way Kambas Game Reserve, Sumatra, elephants feed on 51 plant species (Santiapillai & Suprahman, 1986). Sukumar (1985) enumerated 112 plant species constituting elephant diet in south India. Sivaganesan and Bhushan (1986) has listed 36 species in the diet of elephants in Andhra Pradesh. The results of present study have indicated that elephants in the Rajaji feed on 38 plant species. On considerations of immense differences in geographical and ecological conditions prevailing in African habitats, it is not feasible to compare the results of present study on the dietary spectrum of elephants. However, the results of studies carried out on Asian elephants can to some extent be compared as far as number of food plant species are concerned. The number of plant species in the diet seems to be a function of overall diversity of habitat types and plant species available within the ranging area of elephants. A higher number of plant species in the diet of elephants in Malayan rain forests is expected on considerations of higher floral diversity in rain forests. Elephants in south India range over much larger area as compared to Rajaji and therefore it is expected that they utilize varied habitat types and hence have a wider dietary spectrum.

It is important to consider that certain plant species such as *Ziziphus oenoplia, Lantana camara,* and *Cassia fistula* listed by Sukumar (1985) as elephant food plant species are also found in the Rajaji but have never been observed eaten by elephants. Now the question why do elephants feed on certain plant species in one region and not in other is difficult to answer. However, the scarcity of desired food plant species in an area may force an animal to feed on undesirable plant species appears to be the only apparent reason. *Lantana camara* can be regarded as an undesirable food plant species. The reason being the presence of a secondary compound 'Lanteden' that is known to cause disorder in the sheep physiology. Although the effects of 'Lantaden' on elephants are not known, however, its consumption in large quantities may be expected to cause problems in elephants too. Sukumar (1995) reported that elephants once avoided *Lantana,* off late have started feeding on it sporadically. *Lantana camara* occurs in high densities in certain parts of the Rajaji but elephants were never observed feeding on it.

There are only few studies on relative consumption of different plant parts, which have come to my notice. Lewis (1986) working on the African elephants has distinguished between three parts; branches without leaves, branches with leaves and leaves only. Barnes (1982) estimated that the bark formed only a fraction of diet but did not describe the consumption of other parts of plants in the diet of elephants. The results of the present study revealed that the consumption of bark was much higher as compared to other plant parts, branches and leaves and this is probably the first such report. However, according to Sukumar (1985) elephant feeding on bark has not yet been explained satisfactorily. What induces elephants to feed on bark seems to be difficult to explain but some workers have speculated on possible reasons and there seems no unanimity of views on the subject. Bax and Sheldrick (1963) described that bark eating is in search for calcium. Laws *et al.* (1975) worked out a positive correlation between extent of debarking by elephants and the calcium contents of that plant species. However, McCullagh (1969) analysed the stomach contents of elephants in Murchison Falls National Park and concluded that debarking was not in search of calcium. In yet another study, Anderson and Walker (1974) found no relationship between the extent of bark consumption and its mineral contents. Sivaganesan (pers. comm.) working on aspects of elephant feeding concluded that the consumption of bark was highest in pregnant females in order to meet increased demand of calcium. At this stage it seems difficult to establish whether high bark consumption by elephants in Rajaji was because of its calcium contents. However, it is plausible to accept that feeding on bark is to obtain minerals rather than other components of diet such as protein as in general bark contains more minerals than proteins. One possible reason for higher consumption of bark by elephants in Rajaji could be due to the high demand of certain minerals. This can be further supported by the observations that the proportion of bark in the diet was 70% during monsoon while it reduced to half during summer. Since bark gets enriched by mineral contents due to flow of fresh sap during monsoon and hence was consumed more.

The observations suggest that elephants feed selectively on plant parts of certain species. For instance, they were never observed feeding on *Shorea robusta* leaves.

This might be related to palatability or presence of certain secondary compounds or both.

Probably the first ever study on the impact of the Asian elephant feeding on vegetation was carried out by Muller-Dombois (1972) in which he assessed the crown distortion by elephants. de Jonge (1986) studied the impact of domesticated elephants on vegetation in Mudumalai Wildlife Sanctuary in India. McKay (1973) during his study in Sri Lanka did not detect any significant destructive feeding by elephants. On contrary to this Santiapillai and Suprahman (1986) stated that "elephant is a wasteful feeder judging by the amount of vegetation left uneaten". Ishwaran (1983) reported that elephants cause considerable damage to vegetation and branch breaking, main stem twisting and stem breaking form the most important type of damage evident from the elephant activity. The results of the present study reveal that the main cause of tree mortality was due to pushing over and stem twisting. Complete removal of crown and sever debarking of main stem can cause tree mortality however, such instances were not recorded during the study. The reason of high incidences of pushing over may be related to the lack of browse at convenient height and elephants by doing so, bring the vegetation biomass down to a convenient height at which strain free browsing on young terminal shoots , rich in nutrient is possible. Elephants, in general, by causing moderate tree mortality open up forest canopy leading to growth of saplings and may help in maintenance of healthy populations in forest stand. However, this does not seem to be happening in the Rajaji. Heavy tree mortality by elephants, repeated fire and cattle grazing do not allow quick regeneration and poses major problem for regeneration. This feature not only reduces the food availability but also encourages growth of fire resistant plants and fast growing weeds like *Lantana camara, Cassia tora* and *Parthenium ajacus* etc. leading to degradation of habitat.

It is evident from several studies that elephant feeding may produce enormous impact on vegetation. Buechner and Dawkins (1961) indicated that several vegetation stands in Kabala National Park Uganda are in the process of conversion into tree less grassland through the combined action of elephants and fire. Wing and Buss (1970) concluded that elephant feeding influence the species composition while Guy (1989) reported that several species have disappeared from the canopy layer and tree densities have reduced due to elephant feeding on them. Sivaganesan (1995) observed high mortality to certain tree species in south India. During the present study, 8% of the available food trees were found damaged by pushing over, crown breaking, stem twisting and debarking. Mortality was recorded in 5% of all available food trees mainly due to pushing over and stem twisting. The overall mortality rate does not seem to be too high that can adversely affect tree population. However, the mortality to individual tree species is more important than the overall mortality to all species. The examination of data revealed that the mortality to certain tree species ranged between 6% and 8% of their availability. Sivaganesan (1995) recorded comparatively higher mortality to four preferred food tree species ranging between 8% and 14%, which had caused considerable change in the species composition of forest stand. During present study, it is also expected that tree mortality due to elephant feeding may bring changes in the species composition and densities of forest stands. However, this would depend upon the regeneration status of these tree species. The perusal of the data on population structure of tree species in which mortality (pushing over and stem twisting) was 5% or more (Table 6.5), suggest that the population structure of *Mallotus philippensis, Bauhinia malabarica* and *Ehretia laevis* are of expanding type with good regeneration, while populations of *Aegle marmelos* and *Garuga pinnata* seems to adversely affected by elephant feeding. The mortality in *Dalbergia sissoo* was recorded only 3 % but due to poor regeneration of *Dalbergia* it is expected that elephant feeding would adversely affect the population of this species.

Studies on food preference indicate that elephants do discriminate between species while feeding. Wing and Buss (1970) concluded that elephant prefer certain species probably due to distaste for others. In most studies carried out on Asian elephants there is a mention of preferred food plants (McKay, 1973; Sukumar, 1985; Olivier, 1987; Sivaganesan, 1985), however the preferred food species were those, which were eaten more frequently. It is not necessary that if a species form bulk of the diet it is preferred also. During the present study out of 27 species only 4 of them were eaten in higher proportion to their availability (preferred) while rest of them were either consumed in proportion to their availability or less. The question why certain species are preferred and other are not is difficult to answer.. However, this can be examined in context of herbivores in general. Bailey (1982) however, concluded that nutritional problems of wild herbivores are usually due to lack of good quality food and that animals subsist on non palatable and poorly digestible foods when their preferred foods are scarce or absent. This leads to conclusion that food quality, palatability and digestibility are important factors in food selection. The other factors influencing the herbivores food selection or preference are:

i) Animals' changing nutritional requirements at different developmental stages of life.

ii) Variations in physiological requirements between the sexes

iii) Seasonal variation in the nutritive values of different food plant species.

iv) Availability, abundance of different food items at convenient locations and the animals' access to them.

v) Differences in their abilities to ingest and digest various types of food.

vi) Presence of secondary compounds and latex.

Since the information of elephants' food preference is lacking and the results of present study are not deep enough to lead to any firm and definite conclusion therefore whatever has been stated above in relation to herbivores in general, seems relevant to elephants too.

6.5 Summary and conclusions

The bulk of elephant diet in Rajaji was composed of browse material. Grasses constitute only about 5% of elephant diet. Such low proportion of grasses in the diet was due to the low availability of grasses in the Rajaji as compared to other elephant areas. There were seasonal fluctuations in the consumption of grasses. Grasses were eaten in higher proportions during monsoon and least during summer. The reasons for seasonal variations in grass consumption were palatability and nutritive values, which differ seasonally. Elephant browse component of diet was comprised of 38 species, of which 33 were recorded eaten through direct observations while rest five species were recorded through evidences. However, the bulk of elephant diet was composed of 10 browse species accounting for more than 70% of the diet. Only four browse species were recorded eaten by elephants in higher proportions while 17 species were eaten in equal proportions and 6 species were consumed in lower proportions to their availability in Rajaji. *Mallotus philippensis, Aegle marmelos, Bauhinia malabarica* and *Stereospermum suaveolens* were the preferred food species of elephants. Among the different plant parts, bark consumption was highest followed by branches and leaves. However, there were seasonal fluctuations in the proportions of different plant parts in the diet of elephants. Pushing over was the most frequent type of damage to the trees caused by elephant feeding and was the reason for tree mortality. Stem twisting was recorded in low percentage, a few trees were also found dead due to this. Other type of damage such as crown breaking and debarking did not cause tree mortality and had minimal impact on trees. The overall mortality caused by pushing over and stem twisting was 5% but the mortality in certain species such as *Mallotus philippensis, Bauhinia malabarica* and *Garuga pinnata* was recorded between 6% and 8%. The populations of tree species such as *Aegle marmelos, Garuga pinnata* and *Dalbergia sissoo* were adversely affected due to mortality inflicted by elephant feeding and poor regeneration. If the damage to these trees continued with the present rate than it is expected that the populations of these tree species would eventually be replaced by other species or would simply reduced to an alarming level in near future.

Table 6.1 Percentage of browse and grass in the diet of elephants among different seasons in Rajaji.

Seasons	% of browse	% of grass
Winter	93.1	6.9
Summer	96.6	3.4
Monsoon	89.0	11.0
Year round	95.1	4.9

Table 6.2 Percent contribution of different plant species in the diet of elephants during different seasons in Rajaji.

Plant species	Percent occurrence in diet			
	Winter N = 386	Summer N = 208	Monsoon N = 225	Year round N = 819
Mallotus philippensis	23.6	21.2	14.0	20.5
Dalbergia sissoo	8.5	3.4	14.6	9.8
Ehretia laevis	10.1	11.9	6.7	8.6
Kydia calycina	Nil	5.1	6.1	7.8
Helicteres isora	4.9	9.3	9.1	7.7
Grewia elastica	5.7	6.2	5.5	5.7
Dendrocalamus strictus	1.6	3.4	11.0	5.0
Grewia hainesiana	1.6	5.1	7.3	3.4
Acacia catechu	3.6	2.5	3.7	3.3
Bauhinia purpurea	3.1	0.8	0.6	2.4
Lagerstroemia parviflora	1.0	5.1	2.4	2.2
Ficus rumphii	2.1	5.9	1.2	2.2
Aegle marmelos	0.3	3.4	1.8	1.8
Bauhinia malabarica	2.1	1.7	Nil	1.3
Lannea coromandelica	2.6	Nil	0.6	1.3
Garuga pinnata	2.3	Nil	0.6	1.6
Grewia optiva	1.8	0.8	Nil	1.3
Shorea robusta	2.3	0.8	Nil	1.3
Albizia lebbeck	Nil	4.2	1.2	1.3
Ziziphus xylopyra	1.6	0.8	0.6	1.1
Bombax ceiba	0.8	Nil	1.8	0.9
Sterculia villosa	0.8	0.8	0.6	0.9
Ficus benghalensis	0.8	0.8	0.6	0.7

Millettia extensa	0.5	2.5	Nil	0.7
Ougeinia oogeinsis	0.8	Nil	1.2	0.6
Bridelia squamosa	1.1	Nil	Nil	0.6
Celastrus paniculatus	0.5	Nil	Nil	0.5
Stereospermum chelonoides	0.5	Nil	0.6	0.4
Bauhinia vahlii	0.6	Nil	Nil	0.2
Ficus racemosa	0.3	Nil	Nil	0.1
Syzygium cumini	Nil	0.8	Nil	0.1
Wrightia arborea	0.3	Nil	Nil	0.1
Litsea glutinosa	0.3	Nil	Nil	0.1
Grass spp.	6.8	2.5	7.9	4.9

Table 6.3 Percent occurrence of plant parts in the diet of elephants in Rajaji.

Plant parts	Winter	Summer	Monsoon
Bark	64.96	36.79	63.18
Branches	27.93	26.34	18.86
Leaves	7.11	36.96	17.96

Table 6.4 Percent occurrence of plant parts of each food plant species in the diet of elephants in Rajaji.

Plant species	Bark	Branches	Leaves
Acacia catechu	88.9	11.1	Nil
Aegle marmelos	60.0	13.3	26.7
Albizia lebbeck	58.3	17.1	24.6
Bauhinia malabarica	18.2	18.2	63.6
Bauhinia purpurea	55.0	15.0	30.0
Bauhinia vahlii	R	Nil	Nil
Bombax ceiba	100	Nil	Nil
Bridelia squamosa	60.0	20.0	20.0
Celastrus paniculatus	R	Nil	R
Dalbergia sissoo	88.7	10.0	1.3
Dendrocalamus strictus	Nil	2.4	97.6
Ehretia laevis	85.7	8.6	5.7
Ficus benghalensis	43.8	50.6	5.6
Ficus racemosa	Nil	R	Nil
Ficus rumphii	R	R	Nil
Garuga pinnata	84.6	7.6	7.6
Grewia elastica	74.5	8.5	17.0
Grewia hainesiana	75.0	17.9	7.1
Grewia optiva	54.5	36.4	9.1
Helicteres isora	79.4	20.6	Nil
Kydia calycina	84.5	6.9	8.6
Lagerstroemia parviflora	83.3	16.7	Nil
Lannea coromandelica	90.9	9.1	Nil
Litsea glutinosa	R	Nil	Nil

Mallotus philippensis	56.5	38.0	16.7
Miliusa velutina	33.3	50	16
Ougeinia oogeinsis	80.0	Nil	20
Shorea robusta	100	Nil	Nil
Sterculia villosa	71.4	Nil	28.6
Stereospermum chelonoides	Nil	R	Nil
Syzygium cumini	77.71	11.1	11.1
Wrightia arborea	Nil	Nil	R
Ziziphus xylopyra	Nil	R	Nil

R = recorded but the sample size was very small

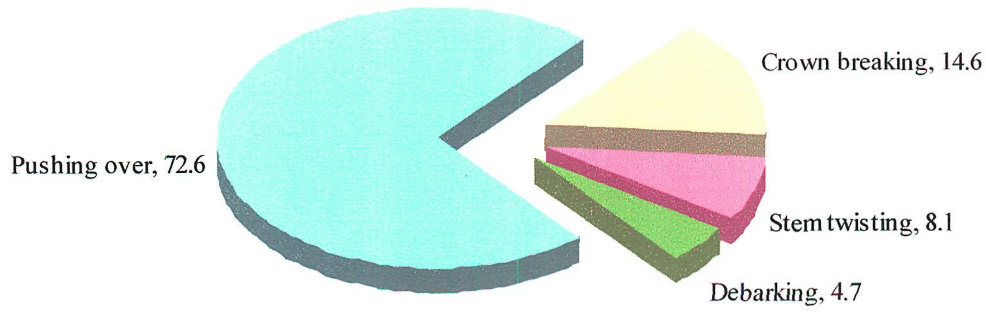


Fig. 6.1 Percentage of trees affected by different damage types.

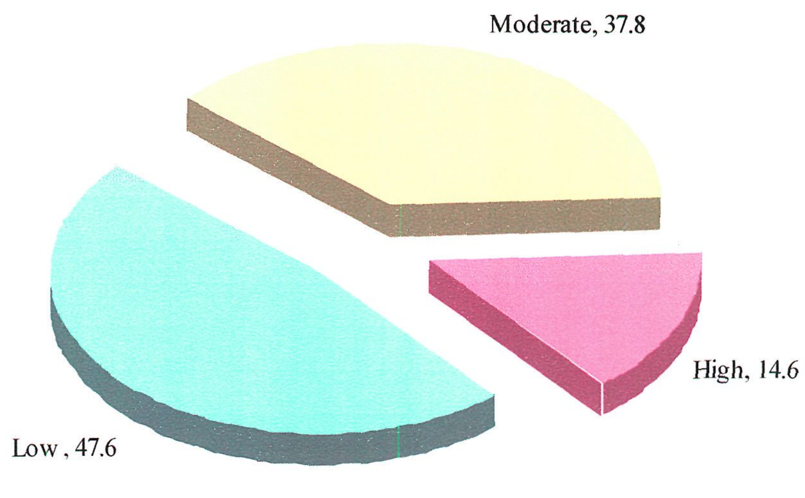


Fig. 6.2 Percentage of trees damaged under different categories of crown breaking.

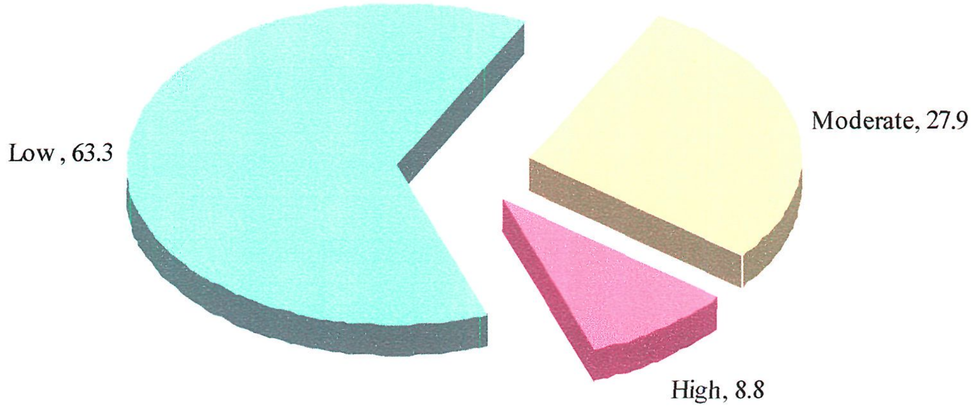


Fig. 6.3 Percentage of trees damaged under different categories of stem twisting.

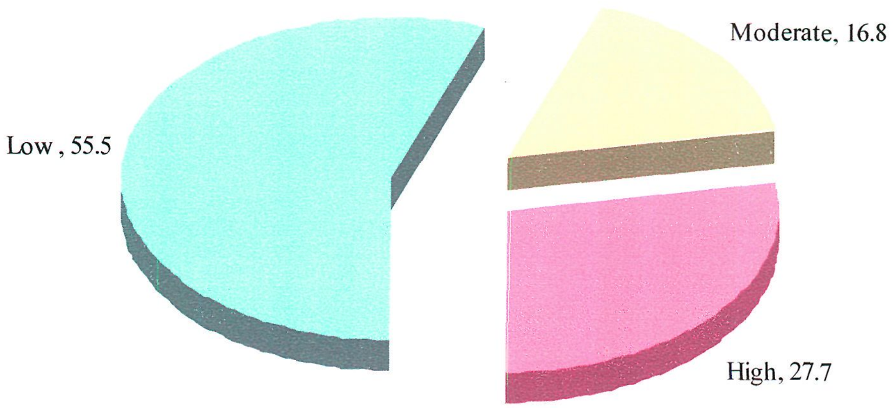


Fig. 6.4 Percentage of trees damaged under different categories of debarking.

Table 6.5 Densities of available and damaged elephant food tree species and percent damage among different damage categories in Rajaji.

Plant species	Trees/ha		% trees damaged				
	Availability	Damaged	Crown breaking	Stem twisting	Pushing over	Debarking	Total damage
Mallotus philippensis	30.3	4.48	3.23	1.16	7.36	3.18	14.9
Aegle marmelos	2.01	0.25	0.82	1.65	5.78	4.13	12.4
Bauhinia malabarica	4.39	4.40	0.75	1.13	6.82	0.37	9.1
Garuga pinnata	3.84	0.15	Nil	1.01	8.08	Nil	9.1
Ehretia laevis	19.96	1.75	1.76	1.73	5.18	0.08	8.8
Grewia hainesiana	5.68	0.45	1.17	1.17	5.55	Nil	7.9
Ficus benghalensis	0.55	0.05	6.00	nil	nil	3.00	9.0
Albizia lebbeck	2.10	0.16	2.37	5.53	Nil	Nil	7.9
Limonia acidissima	0.54	0.03	Nil	Nil	4.40	2.20	6.6
Ziziphus xylopyra	10.27	0.68	2.77	0.98	2.28	0.16	6.5
Dalbergia sissoo	23.80	1.41	Nil	0.21	3.09	2.59	5.9
Bridelia squamosa	0.18	0.01	Nil	Nil	5.50	Nil	5.5

Ficus racemosa	0.55	0.03	Nil	Nil	Nil	5.40	5.4
Sterculia villosa	0.19	0.05	1.80	Nil	3.60	nil	5.4
Lannea coromandelica	1.64	0.08	0.96	nil	3.92	nil	4.9
Kydia calycina	14.46	0.62	0.22	0.46	3.40	0.22	4.3
Ficus virens	0.92	0.03	Nil	Nil	1.60	1.60	3.2
Flacourtia indica	1.10	0.03	1.35	Nil	1.35	Nil	2.7
Ougeinia oogeinsis	21.06	0.42	0.53	0.30	1.15	Nil	2.0
Bombax ceiba	4.20	0.06	Nil	Nil	Nil	1.40	1.4
Acacia catechu	38.08	0.50	Nil	0.17	0.78	0.34	1.3
Lagerstroemia parviflora	10.83	0.13	0.60	0.15	0.45	Nil	1.2
Bauhinia purpurea	14.28	0.13	Nil	0.90	Nil	Nil	0.9
Emblica officinalis	1.09	0.01	Nil	0.91	Nil	Nil	0.9
Grewia elastica	1.10	0.08	0.78	Nil	Nil	Nil	0.8
Stereospermum suaveolens	1.28	1.01	Nil	0.78	Nil	Nil	0.8
Xeromphis spinosa	1.64	0.01	0.60	Nil	Nil	Nil	0.6

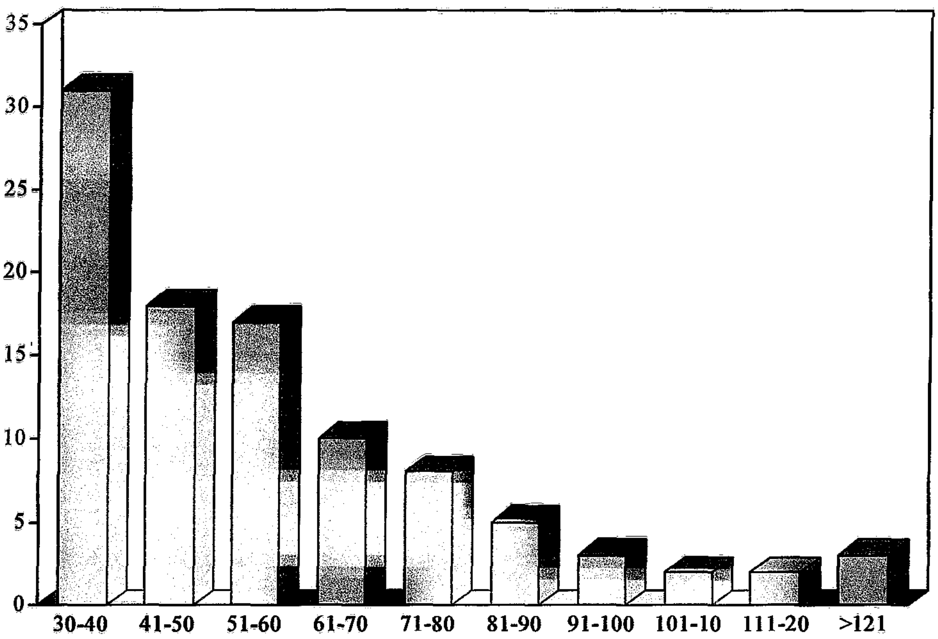


Fig. 6.5 Percent trees affected by different damage types among ten girth classes.

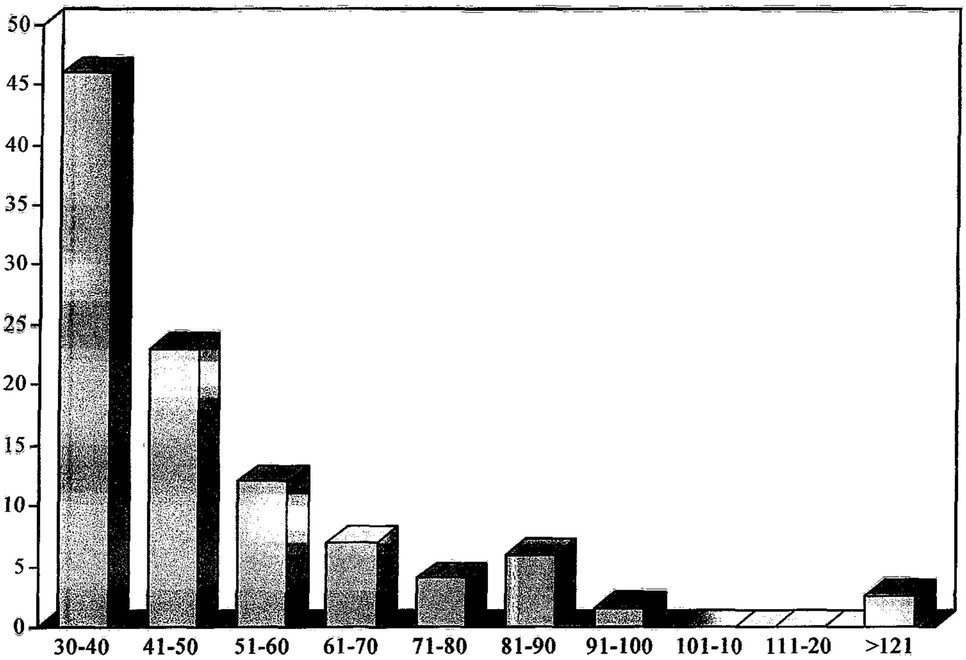


Fig. 6.6 Percent trees affected by crown breaking among ten girth classes.

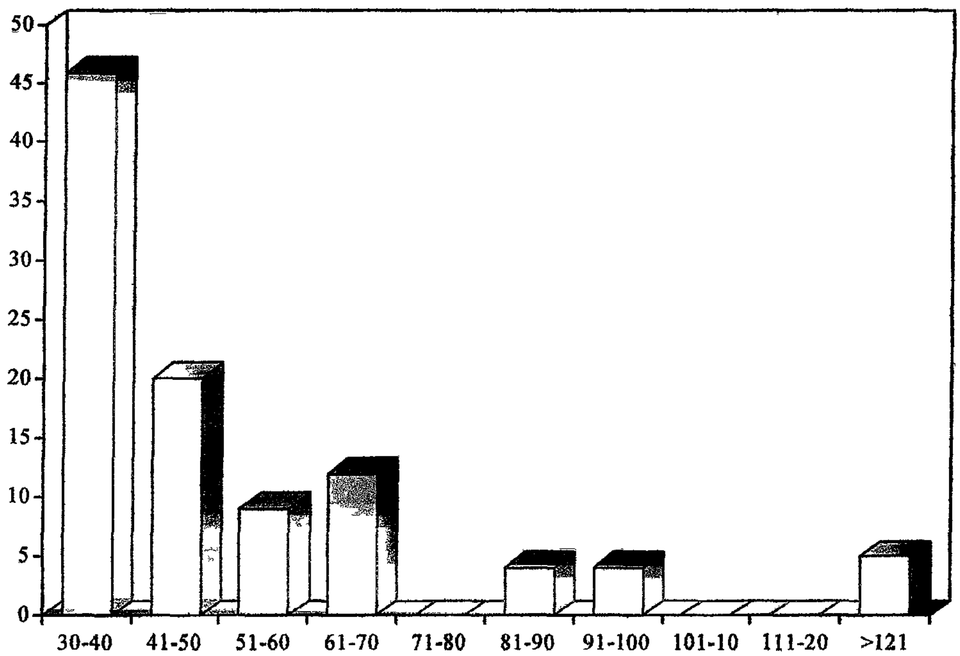


Fig. 6.7 Percent trees affected by stem twisting among ten girth classes.

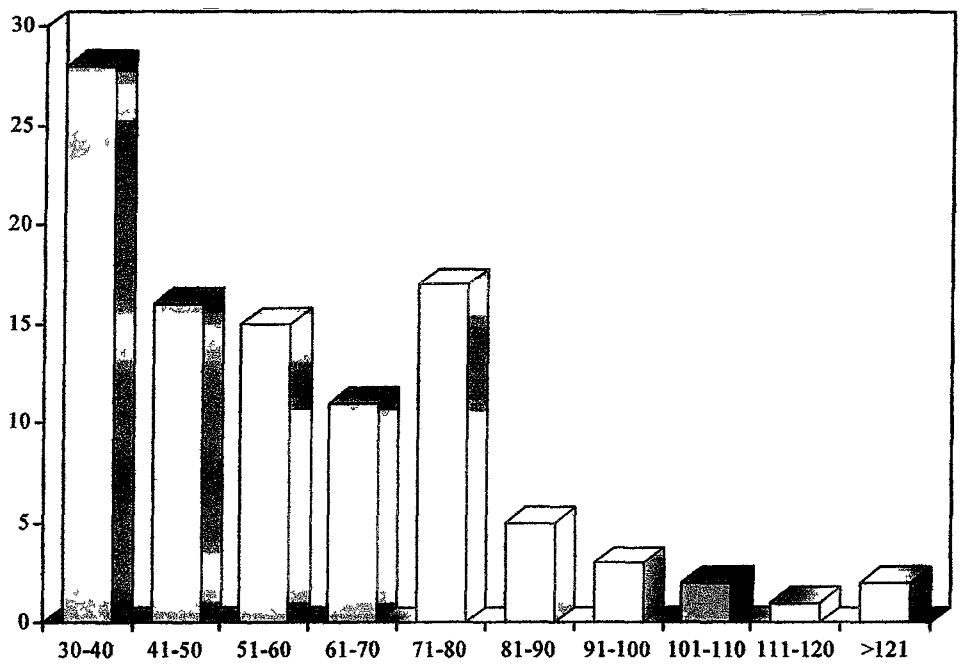


Fig. 6.8 Percent trees affected by pushing over among ten girth classes.

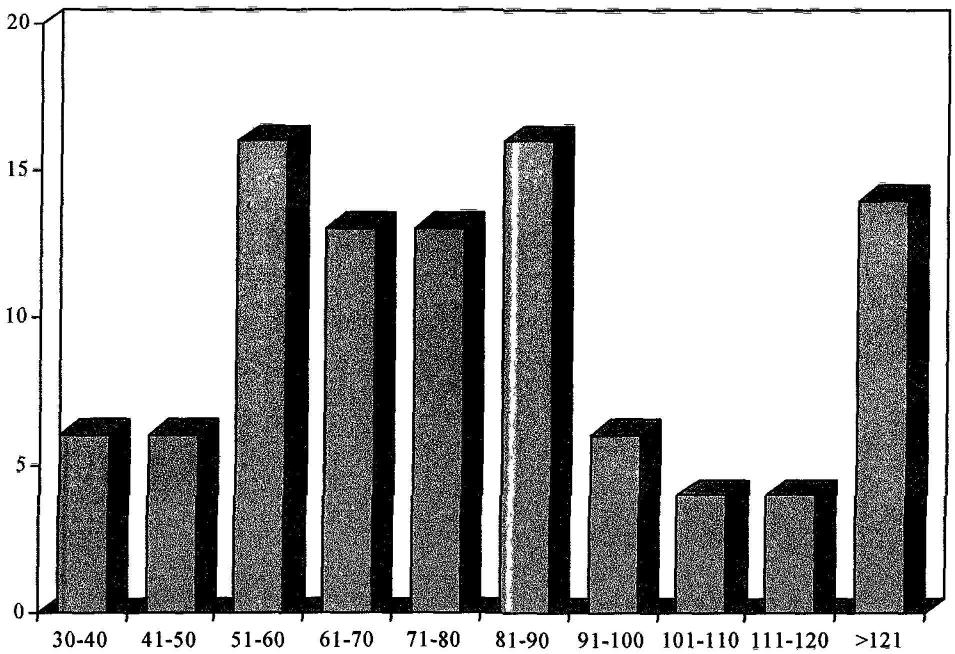


Fig. 6.9 Percent trees affected by debarking over among ten girth classes.

Table 6.6 Proportional availability (P_{io}) and utilization (P_{ie}) of different plant species by elephants in Rajaji.

Plant species	P_{io}	P_{ie}	95% confidence intervals			Significance
			Lower limit		Upper limit	
Mallotus philippensis	0.1402	0.2635	0.1646	≤P1≥	0.3624	+
Aegle marmelos	0.0093	0.0147	0.0123	≤P2≥	0.0417	+
Bauhinia malabarica	0.0203	0.2588	0.1604	≤P3≥	0.3571	+
Garuga pinnata	0.0177	0.0088	-0.0121	≤P4≥	0.0298	0
Ehretia laevis	0.0923	0.1029	0.0347	≤P5≥	0.1711	0
Grewia elastica	0.0262	0.0264	-0.0095	≤P6≥	0.0625	0
Ficus benghalensis	0.0025	0.0029	-0.0092	≤P7≥	0.0151	0
Albizia lebbeck	0.0097	0.0094	-0.0122	≤P8≥	0.0310	0
Limonia acidissima	0.0024	0.0017	-0.0076	≤P9≥	0.0111	0
Ziziphus xylopyra	0.0475	0.04	-0.004	≤P10≥	0.084	0
Dalbergia sissoo	0.1101	0.0829	0.0210	≤P11≥	0.1448	0
Bridelia squamosa	0.0008	0.0005	-0.0048	≤P12≥	0.0060	0
Ficus racemosa	0.0025	0.0017	-0.0076	≤P13≥	0.0111	0

Sterculia villosa	0.0008	0.0029	-0.0092	≤P14≥	0.0151	0
Lannea coromandelica	0.0075	0.0047	-0.0106	≤P15≥	0.0200	0
Kydia calycina	0.0669	0.0364	-0.0056	≤P16≥	0.0785	0
Ficus virens	0.0042	0.0017	-0.0076	≤P17≥	0.0111	0
Flacourtia indica	0.0050	0.0017	-0.0076	≤P18≥	0.0111	0
Ougeinia oogeinsis	0.0974	0.0247	-0.0101	≤P19≥	0.0595	-
Bombax ceiba	0.0194	0.0035	-0.0097	≤P20≥	0.0168	-
Acacia catechu	0.1762	0.0294	-0.0085	≤P21≥	0.0673	-
Lagerstroemia parviflora	0.0501	0.0076	-0.0119	≤P22≥	0.0272	-
Bauhinia purpurea	0.0660	0.0076	-0.0119	≤P23≥	0.0272	-
Emblica officinalis	0.0050	0.0005	-0.0048	≤P24≥	0.0060	0
Grewia elastica	0.0050	0.0047	-0.0106	≤P25≥	0.0200	0
Stereospermum suaveolens	0.0059	0.0594	0.0063	≤P26≥	0.1124	+
Xeromphis spinosa	0.0075	0.0005	-0.0048	≤P27≥	0.0060	-

+ = utilization is more than the availability in the habitat (indicating preference).
- = utilization is less than the availability in the habitat (indicating avoidance).
0 = utilization in proportion to the availability in the habitat (indicating neither preference nor avoidance).

Chapter 7: Social Organisation

7.1 Introduction

The social organization of the Asian elephants has not been a subject of in-depth study as it has been in case of the African elephants. The social organization of the African elephants has been investigated by several workers using long-term monitoring of individuals and groups, e.g. Douglas-Hamilton (1972), Douglas-Hamilton and Douglas-Hamilton (1975), Laws *et al.* (1975), Moss (1981) and Poole and Moss (1981). The study by McKay (1973) on the levels of social organization and behaviour of the Asian elephants can be considered as pioneering in which he has sketched out the underlying sociality within elephant groups. A decade later Sukumar (1985) described the grouping pattern among elephants in south India. However, both these studies were based on a small sample size.

Formation of groups by animal species reflects the relationship between the members of the group. The relationships among members of an animal species can be viewed in two ways; a mare aggregation of individuals, which is based on chance encounters, as witnessed among several small and medium size ungulates and a definite hierarchical relationship between individuals under the considerations of Kinship theory. The work on the African elephants showed that they exhibit the latter pattern. It is presumed, that the Asian elephants also follow the similar pattern of social organization to that of the African ones. However, this presumption is not based on the kind of long-term studies, which have been carried out for the African elephants. In this chapter, I have tried to examine the group structure, factors influencing the group structure and the levels of relationship between the individuals within the groups of elephants. The present study is also subjected to several limitations as have been faced by the earlier workers, however I have advanced the earlier studies by providing more quantitative information on the dynamics of group structure and have examined the underlying sociality with relatively larger sample size and therefore expected to provide a much clearer view on the subject.

7.2 Methodology

Data on group structure and group dynamics were collected by observing individuals in the field. Following procedure was adopted in collecting field data and in defining various terms used in this chapter.

7.2.1 Field data collection

The data on group structure, size and group dynamics were collected whenever a group of elephants or a solitary individual was located and observed. The numbers of individuals in a group were enumerated and efforts were made to record age category and sex of each member of the group. Only those sighting of groups were included in calculating mean group size where total count of a group was obtained. At several occasions, it was not possible to record age categories and sex of all individuals in a group due to either compactness of the group or thick vegetation cover, poor visibility or for any other reasons. Such groups were not included in the analysis pertaining to the group dynamics. Following criteria were used to classify individuals in to different age categories:

1. Adult male: a mature male of the age of 15 years and above.
2. Adult female: a female of the age of 12 years and above.

3. Sub-adult male: a male below the age of 15 years and above the age of 5 years.
4. Sub-adult female: a female below the age of 12 years and above the age of 5 years.
5. Small calf: a calf up to one year of age.
6. Large calf: a calf between the age of 1 year and 5 years.

The estimation of exact age is difficult in the field, and the above classification is tentative. However, considering the rate of growth and age relationship as described in the literature, the estimation was done in the field based on the height of individuals. Normally a mature male of 15 years attains a height of about 7 feet while an adult female of about 12 years of age attains a height of about 6.5 feet. Male and female smaller than these heights and independent of mothers were classified as sub-adults. A juvenile, which can fit under the belly of the mother was termed as small calf, while the one which can not be accommodated under the belly but remains attached with the mother most of the time and less than the height of a sub-adult was classified as large calf. Due care was taken in recognizing above mentioned age categories but chances of error can not completely be ruled out especially in classifying adult and sub-adult females and large calf and sub-adults.

A group was defined as any aggregation of individuals irrespective of size, age and sex performing any activity (moving, resting feeding etc) in a coordinated manner. I have used the term 'group' rather than employing other terminologies like family unit, herd, clan, nursing group, juvenile care group etc used by several earlier workers e.g. Medway (1965), Khan (1969), Stevens (1968), Mckay (1973), Vancuylenberg (1974), Olivier (1978) and Sukumar (1985), which are either confusing or inconsistent. A group was differentiated in to the following categories in order to understand the underlying associations between individuals within a group.

1. Male group: A group consisting of only males or a solitary male.
2. Male–female group: A group consisting of adult and sub-adult males and females.
3. Cow-calf group: A group comprised of adult and sub-adult females and calves.
4. Mixed group: A group consisting of adult male(s) along with cow-calf group.

Two males were radio-collared in Rajaji Sanctuary one each in 1986 and another in 1987. Two females (one each in Rajaji and in Chilla.) in different groups were also radio-collared in 1988. All four elephants were tracked on foot on almost daily basis and whenever the initial eye contact with the group was established, the group composition and structure was recorded only once on any day. Apart from this, whenever other elephants (either solitary or group) were encountered the data on the group size and structure were recorded. In addition to this, data on the habitat parameters at the location of a group were also recorded which included terrain, vegetation type and distance to the nearest water source. Adult males, whether seen solitary or associated with female group were excluded while calculating mean group size. Only groups consisting of females, sub-adults and calves were included. The results summarized in the following section are based on the multiple sightings of the solitary individuals and groups as well as the sightings of discrete solitary individuals and groups. Only daytime sightings were recorded. All associations described in the following sections are based on the group composition and size in the study area.

7.2.2 Data analysis

Data analysis included calculation of mean group size, standard deviation and minimum and maximum group size values. Chi-squire goodness of fit was used to test the differences in the distribution of frequency of sightings between different types of elephant groups. Although the values of mean group sizes are presented in the chapter, the differences in group size vis-à-vis seasons and habitat have been tested using non parametric Kruskal-Wallis One-Way ANOVA (K-W χ^2) and the Kolmogorov-Smirnov tests. All calculations and analysis were carried out using SPSS for windows (version 10.0).

7.3 Results

In all, 1132 observations on groups were made between 1986 and 1989 including multiple observations on the radio-collared individuals and other chance encounters with either solitary individuals or groups. The frequencies of sighting of two radio-collared male elephants (MR1 & MR2) were 259 and 171, while the frequencies of sightings of two radio-collared females in two different groups (RFG & CFG) were 145 and 180 respectively. Apart from the radio-collared animals, there were 377 sightings. These also included the multiple sightings of certain groups. However, it is difficult to ascertain which particular group was seen on how many occasions as no attempt was made to identify the groups or individuals based on their morphological characteristics. It is possible that sightings of some groups were more frequent than the others and some other groups were seen only once.

7.3.1 Group size

A total of 454 groups those fulfilled the criterion as mentioned in the preceding section of methodology were included in calculation of mean group size. The overall mean group size was 7.96 ± 5.38. There were marginal differences in the mean group size between different seasons (Table 7.1). Comparatively larger mean group size was recorded in summer (8.37 ± 6.05) as compared to that of winter (7.8 ± 5.23) and monsoon (7.66 ± 4.26). However, the seasonal difference in the median group size was not statistically significant (K-Wχ^2 = 1.07, d.f. = 2, P >0.05).

The median group size of elephants differed significantly between Rajaji and Chilla (Kolmogorov-Smirnov Z = 4.502, P< 0.01). The mean group size was 9.05 ± 5.26 (n = 420) in Rajaji and 5.54 ± 4.82 (n = 188) in Chilla. There were however, no significant differences in the median group size between different terrain and vegetation types. Larger groups were observed in the vicinity of water sources as compared to the areas away from the water sources; however, the difference was not significant.

The group size ranged between 2 and 48. About 90 percent of groups were recorded comprising of 13 or fewer individuals. The maximum frequency of sighting was recorded of groups consisting three individuals. Proportionately higher frequency of sightings were recorded in group size between 2 and 13 as compared to larger groups (Fig. 7.1) and the differences were significant (χ^2 = 481.1, d.f. = 28, P <0.01).

7.3.2 Group dynamics

Observations on 1078 elephant groups revealed that the proportion of all male groups and mixed groups were significantly higher as compared to the male-female and cow-calf groups (χ^2 = 645.5, d.f. = 3, P<0.01) There were 499 (44%) male groups and 456 (40%) mixed groups while male-female and cow-calf groups were 61 (5.4 %) and 62 (5.5%) respectively (Fig. 7.2).

7.3.2.1 Male groups

All male groups (82%) were mostly comprised of a solitary male (n = 409). The groups of two males were proportionately less (n = 79) while the groups of three individuals were encountered only on 3 occasions and an aggregation of seven males was recorded only on single occasion (Fig. 7.3) in the study area. Chi-square test revealed a significant difference in the occurrence of male groups among different group size categories (χ^2 = 1240, d.f. = 4, P< 0.01).

The model group size in all seasons remained one. Out of the total 171 sightings of male groups in winter, 84.2 percent groups were of solitary male, 14.6 percent groups were of two males and only 1.1 percent groups were comprised of three males. More or less similar situation existed in summer and monsoon as well where the percentage of solitary male was much higher (84.5 % and 77.1% respectively) as compared to the other group size categories (Table 7.2). There was marginal difference in the mean group size among different season. It was 1.17 in winter, 1.19 in summer and 1.29 in monsoon (Table 7.3). The differences were however not significant in median group size (K-W χ^2 = 4.1, d.f. = 2, P > 0.05).

7.3.2.2 Male –female groups

A total of 61 male-female groups were observed which comprised of only 5.6 % of the total groups encountered during the study. The group size ranged between a minimum of two and a maximum of 17 individuals (Fig. 7.4). Among the various categories of group size, maximum groups were recorded in the lower group size categories. About 88 percent of all male-female groups were in the group size of 5 or fewer individuals while only 1 to 3 percent groups were between the group size 6 and 17. The number of groups were proportionately higher in the group size of 2 and 3 individuals as compared to the other categories of group size and the difference was significant (χ^2 = 92.9, d.f. = 9, P <0.01).

The maximum frequency of sightings in all seasons was of the groups of 2 and 3 individuals. During summer a maximum of 13 groups (68%) were encountered with just one male and one female while in winter and monsoon the maximum sightings were of 3 individuals mostly two females and a male (Table 7.4). The overall mean group size was 3.7. Comparatively higher mean group size was recorded during winter (5.8) as compared to summer and monsoon (Table 7.3) and the seasonal variation in the median group size was significant (K-W χ^2 = 13.4, d.f. = 2, $P < 0.01$).

7.3.2.3 Cow-calf groups

Cow-calf groups accounted for 5.7 percent (n = 62) of the total groups encountered. Proportionately more number of groups were recorded in smaller group size categories as compared to the larger group size categories (χ^2 = 69.4, d.f. = 6, $P< 0.01$). Maximum number of groups were recorded in the group size of two individuals (n = 30) while half of it were recorded in the group size of three individuals (n = 15). The number of groups ranged between two and eight among various group size categories (Fig. 7.5).

The overall mean group size of cow-calf groups was 3.16. Slightly larger mean group size was recorded during summer (3.4) than in winter (2.9) and monsoon (3.2), however, the differences in the median group size among three seasons were not significant (K-W χ^2 = 5.37, d.f. = 2, $P>0.05$). Table 7.3 provides information on the seasonal variation in the mean group size. The frequency sightings of groups, comprising of a female with its one calf was highest during winter and summer, while in monsoon the maximum frequency sighting was of a group comprising either one female with one calf and a sub-adult or two females with just one calf. Only once a group of 8 individuals was recorded comprising of 7 females and only one calf during summer (Table 7.5).

7.3.2.4 Mixed groups

About 42 percent of the total groups recorded were of mixed type. The group size ranged between 3 and 52 (Fig. 7.6). Smaller groups (group size of 3 to 13 individuals) were significantly higher as compared to the larger groups (χ^2 = 505.8, d.f. = 29, P<0.01). There was a marginal variation among the mean group size across different seasons. Higher mean group size was recorded in summer (10.8) as compared to winter (9.9) and monsoon (8.7), however, the differences in median group size were not significant (K-W χ^2=5.94, d.f. = 2, P>0.05). Comparatively higher sighting frequencies were recorded of group size classes 4, 7, 9, and 11 during winter as compared to the other categories of group size. In summer these were of the group size 3, 8, 11 and 12 and during monsoon higher frequencies of sighting were recorded of the group sizes 3, 6, 8,9 and 13 (Table 7.6).

7.3.3 Grouping Pattern and social organisation

Detailed observations were made on two radio-collared males (MR1 & MR2) and two discrete female groups (RFG & CFG) to understand the role of male in the society of elephant and to see the social bonds between different individuals within a group. Here the female group is referred to any group comprised of at least a female along with any other individual irrespective of sex and age and hence it differs from the definitions given in the preceding sections.

The group structure of MR1 and MR2 were recorded on 237 and 135 occasions, respectively and the data revealed that both the males remained mostly solitary. MR1 remained as a loner on 163 occasions and it was observed in the company of female groups on 74 occasions. The analysis of data did not reveal any significant seasonal difference in the grouping pattern of MR1 (χ^2 = 5.22, d.f. = 2, P>.05), however it was accompanying more with female groups during summer (n = 29) than in winter (n = 22) and monsoon (n = 23, Fig. 7.7). MR2 was never observed in the company of female groups during winter, while on 2 and 4 occasions it was observed accompanying female groups during summer and monsoon respectively (Fig. 7.8).

Contrary to the above, more female groups were observed accompanying adult male(s) as compared to the groups those were without an adult male. Out of the 579 sightings of female groups, 351 (about 60%) groups were with adult male while only about one third (n = 288) groups were without an adult male. During winter and summer, proportionately more sightings were recorded where female groups were accompanying adult male as compared to monsoon (Fig. 7.9) and the differences were significant ($\chi^2 = 9.15$, d.f. = 2, P<0.01).

In order to understand the social bonds between the individuals of a group, the detailed observations on a female group (CFG) revealed that the group structure and size both were dynamic entities and kept on changing. The group size ranged between 2 and 48 individuals, however, about 93 percent times this group was observed in a group of up to 9 individuals. Maximum sightings were of groups comprised of three individuals (n = 38 or 21.1%) and it was followed by the sightings of groups of two (n = 29 or 16.1%) and equal number of sightings were of groups composed of 4 individuals. On all occasions, one female along with a small calf constituted a group of two individuals. A group of three on most occasions was composed of one adult female and its calf plus a sub-adult male while the group of 4 was mostly comprised of two adult females, one sub-adult male and a calf. The rest of the sightings of groups containing 5 to 9 individuals were due to the additions of either sub-adults or the females. The sightings of larger groups were minuscule as compared to the sightings of small groups (Fig. 7.10). Considering the frequencies of group size it appeared that composition of small groups was fairly stable, however further examination of the data suggested otherwise. Based on 107 sightings, which were obtained more or less continuously, only on few occasions the group composition remained same for few days. For instance, the longest association of same individuals in the group was recorded for 19 continuous days when this group was comprised of four individuals; two adult females, one sub-adult male and a small calf. On another occasion three individuals, one female along with one sub-adult male and a calf remained together for five consecutive days while rest of the time the group structure kept on changing on either daily or after two to three days. Another female group (RFG) showed a different grouping pattern. The group size ranged between 3 and 33 individuals (Fig. 7.11). About 58 percent sightings were of groups containing 9 to 12 individuals. Maximum sightings were of groups comprised of 12 individuals, however, the group composition kept on changing. For instance on one occasion this group was observed comprised of four females, one calf and seven sub-adults while the next day it was observed having five females, five calves and two sub-adults. On no occasion, the group composition of RFG remained the same for more than two days. The changes in the group composition and size were more frequent in case of RFG as compared to the CFG.

7.4 Discussion

7.4.1 Group size and structure

In the absence of an in-depth study on the social organization of Asian elephants, it has been presumed that the Asian elephants do exhibit a social organization similar to their African counterparts. Laws *et al.* (1975) have suggested that among African elephants, the basic unit is of about 6 individuals comprised of an adult female along with her daughters and juveniles and the larger herds are the results of aggregation of several related basic units. They have also observed the distinct peaks at group sizes 6, 11, 17 and 23, which they termed as polymodal frequency distribution. McKay (1973), working on Asian elephants in Gal Oya, Sri Lanka observed relatively higher frequencies of groups comprising of 2 to 12 individuals. The maximum observations were of the group size of 2. Olivier (1978), working in Malayan rain forest observed significantly higher frequency of group sizes 3, 5 and 7 while, Sukumar (1985), described the strong tendency of Asian elephants to form groups of 3 and 7 individuals. Furthermore, he also indicated peaks at group size 3, 6, 9 and 12 but he cautioned that this can not be treated as polymodal frequency distribution as the peaks were faintly indicated and the results were based on a small sample size. The results of present study are in conformity with other studies on Asian elephants suggesting that Asian elephants do not show affinity with their African counterparts as far as polymodal frequency distribution of group size is concerned. The above-mentioned studies on group size including the present one are also in agreement that Asian elephants form small groups as most of the groups (about 90%) were of 12 or fewer individuals at all the study sites mentioned as above.

It is generally believed that African elephants form larger groups as compared to the Asian ones; however, it is not true, as African elephants have also been observed forming small groups. For instance, Merz (1986) reported the mean group size in Tai National Park as 3.4 ± 1.6 while McKnight (2000), reported the median group size from Tsavo East National Park as of 6 individuals and the mean group size as 7.8 ± 0.41. Owen-Smith (1988), after a thorough review, opined that forest elephants form smaller groups as compared to those of typically savanna elephants, indicating that the habitat structure is one of the factors influencing the group size. Since, Asian elephants are forest dwellers and hence form small groups, which is evident from the studies of McKay (1973), Olivier (1978) and Sukumar (1985) as well as from the results of the present study. Why do elephants form smaller groups in forests than in savanna? This may possibly be because elephants' society is highly social and in order to establish social relation between the individuals and maintenance of cohesiveness of group, visual contact is important and to some extent necessary. It is easier to maintain effective visual contact within a large group in an open habitat like savanna than in a closed habitat (forests).

Jarman and Sinclair (1979) opined, considering grouping pattern of several African mammals that group size is a function of availability of resources particularly food and water; when food is scarce the large groups tend to breakup into smaller groups to avoid competition. Similar patterns have also been observed among both African and the Asian elephant populations e.g., Laws (1969), Leuthold (1976), Sukumar (1985) and McKnight (2000), where larger groups were observed during the wet season as compared to the dry months attributing it to the better availability of forage quality and quantity during wet months than in dry months. In case of Rajaji N.P., however, no such variation in the group size was observed and the mean group size remained more or less the same during different seasons. Olivier (1978) observed similar pattern in Malayan rain forest where influence of season was negligible on the group size. Seasonal variation in food availability is more pronounced in grassland and savanna ecosystems than it is in forests. At both the places (Rajaji N.P. and Malayan rain forests) elephant populations are mainly browser and grasses constitute only a fraction of elephants' diet. The seasonal fluctuation in the availability of browse is less pronounced as compared to the availability of grasses and hence little noticeable seasonal differences were observed in the mean group size. Comparatively larger group sizes during summer may be due to limited availability of water, and therefore most elephants establish their home ranges around available water sources.

Some animal species form larger groups in response to the stress, harassment and otherwise disturbed due to other reasons (Eltringham & Malpas, 1980; Lewis, 1986; Ruggiero, 1990). Significant variation in the mean group size between Chilla and Rajaji can be viewed in this context. The Rajaji had a high density of Gujjar settlements, human and cattle population as compared to Chilla and this could be the reason enough for elephants to form larger groups in Rajaji as compared to Chilla.

7.4.2. Social organization

Before describing the levels of social organization among elephants, it is important to review various terminologies used by different workers, as there is inconsistency in applying different terms especially in relation to the Asian elephants. For instance, the term "family unit" has been used by Olivier (1978) describing it as minimal basic social unit consisting of few related adult females and their immature offspring while Sukumar (1985) has used this term exclusively to describe one adult female and her immature offspring. The term "herd" has been used in two ways; to represent a social unit as a synonym to the group (Olivier, 1978; Sukumar, 1985) and to represent probably a population or a sub-population (Khan, 1969; Medway, 1965; Stevens, 1968). Similarly, Daniel (1998) has used the term "clan" in place of family unit and he described a clan as a basic unit of elephant society. While Sukumar (1985) has used clan to describe an aggregation of numerous elephant families, in a similar way as it has been used in case of African elephants by Laws and Laws & Parker (1968), Douglas-Hamilton (1972) and Moss (1981). The other terms, which find mention in the literature include, "joint family"- to describe two or more related family units, "infant nursing group" - to describe females along with their newborn and "juvenile care group"- referred to related females along with their non-suckling calves still attached with their mother. Since there is no unanimity in the usage of different terms in earlier literature, I therefore, preferred to stay away from using these terms in order to avoid confusion. As indicated in the earlier section of methodology, I have used the term "group" to describe any aggregation of individuals whether by chance or based on the definite relationship in which the activities of individuals were in a coordinated manner. Further categories such as male group, male-female group and cow-calf groups etc have been described to refer the composition of a group based on the presence of individuals in it.

The review of literature on the social organization of Asian elephants revealed that in almost all studies, two types of groups have been described; male or bull group and female group comprised of adult females along with their immature offspring and the associations between males and between male and family groups have been worked out. However, I feel that the descriptions of other associations such as between males and females and between cow-calf are also important to understand the levels of social organization among elephants and hence groups have been categorized accordingly.

The perusal of data suggested that males after attaining maturity leave their groups and remain most of the time solitary as also discernible from earlier studies of McKay (1973), Olivier (1978) and Sukumar (1985). The two radio-collared males (MR1 and MR2) those were monitored continuously for about a year remained mostly solitary. Out of a total 259 sightings of MR1, on 162 (62%) occasions it was seen solitary, on 17 (6.6%) occasions it was in the company of other males while on 74 (28%) occasions it remained attached with female groups. However, another male MR2 had shown slightly different pattern of its association with other males and female groups. It was observed as loner on 129 (75.4%) occasions, and in the company of other males on 34 (20%) occasions, while remained attached to female groups on only 6 (3.5) occasions. This suggests that males either remain solitary or form male groups and occasionally come in contact with female groups. On the other hand, majority of the female groups were seen in association with adult males. This leads to the conclusion that the association of an adult male either with other males or with female groups is purely due to chance encounters. Both these males did not show any fidelity towards either a particular individual male or a female group, indicating that adult males do not have strong social ties with any particular female group. Similar pattern has also been observed in both; African elephants (Laws *et al.,* 1975; Martin, 1978; Moss, 1981) and among the Asian elephants (Eisenberg *et al.,* 1971; Mckay, 1973; Santiapillai *et al.,* 1985).

Musth in elephants has been termed as analogous to the rut in other ungulates. During Musth, there is a sharp increase in the testosterone level in the blood (Jainuddin *et al.,* 1972 b) and it has been presumed that males during Musth achieve dominance over non-Musth bulls in the area and exhibit heightened sexual and aggressive activity (Owen-Smith, 1988). Musth period generally lasts 2-3 months and usually reoccur once in a year (Eisenberg *et al.,* 1971). During the present study, MR1 was observed in Musth during September, which lasted for about 3 months but after a brief period of about one and a half months, it was again observed in Musth at the end of January, which lasted for about 2 months until March. Another male MR2 was also observed in Musth during March and April.

It has been observed in African elephants that males during Musth are more likely to get attached with female groups than the males during non-Musth (Poole & Moss, 1981). Similar pattern was observed during the present study at least in case of MR1 who was seen in the company of female groups more when in Musth than the non-Musth period. Contrary to that, MR2 was never observed attached to a female group when in Musth. Since the two study males have shown different patterns, therefore, it is difficult to draw a firm conclusion about the effects of Musth on the grouping pattern in the study population. Moreover, the sample size was also not enough to generalize the pattern for a population of about 1000 individuals.

Formations of large male groups have been observed in case of the African elephants. The largest bull group so far reported was of 144 individuals (Owen-Smith, 1988) however, such a large group is probably an exception. Other studies on African elephants have reported much smaller group sizes. For instance, Douglas-Hamilton (1972) reported largest bull group size of 10 individuals from Lake Manyara, Laws *et al.* (1975) reported the same of 11 individuals from Murchison Falls while Croze (1974) observed largest bull group of 18 individuals in Seronera. Male or bull groups are also common in the society of Asian elephants. For instance, McKay (1973) observed largest bull group of 7 individuals in Sri Lanka, Sukumar (1985) however reported male groups up to 3 individuals in south India. During the present study, the largest male group seen was of 7 individuals. Sukumar (1985) has rightly opined that the bull group size is probably a function of the density or the total number of bulls present within an area. Comparatively larger male group size in Rajaji could be because of the presence of proportionately more number of males in the population as compared to south India where due to poaching the number of males have declined. The adult male to female ratio in south India was 1: 1.2 while in Rajaji it was 1:1.7.

There is unanimity in literature, both on Asian and African elephants that the basic unit is of mother, its offspring mostly referred as either family unit or family group that is non-divisible, and large groups are aggregations of related family units. If we strictly follow the above definition than the question arises, as to what happens to those females who are mature and yet do not have offspring. Do they form separate groups and if so then what is the composition of such groups? The perusal of the data suggested that females alone do not form separate groups, however, on two occasions one solitary female was seen and on three occasions a group of two females was encountered. These few sightings of only female groups cannot be taken seriously, as they may be just chance sightings when other members of the group may have been moved away leaving these females behind. However, a sizable number of groups (n=62) was observed comprising of males and females without any calf (Fig. 7.2). The proportion of such groups was about 5 percent, however, if male groups were excluded from the calculations then the proportion of male-female groups became 10.5 percent, which seemed proportional to the availability of young adult females (not yet having any offspring) with in a population. Further analysis of male-female group data suggested that more than 65 percent of groups were of two or three individuals. Groups of 3 individuals were mostly composed of a female with 2 males while larger groups were composed of adult and young adult males and females. This leads to the conclusion that males and females those have just attained maturity or closer to attaining maturity form separate groups of varying sizes and remain mostly in the company of at least an adult male. It is however, difficult at this stage to pronounce the stability and function of such associations due to the lack of long-term monitoring and proper data on the level of interaction between the individuals in such groups. However, it seems probable that the young adult females if separated from cow-calf groups would be able to range over a larger area and would have higher chances to interact with more males than if they do remain with cow-calf groups whose mobility is restricted due to the presence of calves. Secondly, the young adult females are inexperienced and would have more chances of finding a suitable mate in the absence of experienced females.

The assertion that a family unit is composed of one female with her immature offspring and the model group is of three individuals (female + two of her offspring) was examined during the present study. The data on cow-calf groups revealed that most sightings were of 2 individuals (female + one of her offspring). While a group of three individuals was composed of either 2 adult females and a calf or one adult female with one calf and a sub-adult. However, there were fewer sightings of the latter composition. The data on group composition of a cow-calf group (CFG) which was continuously monitored for about eight months revealed that this group was mostly comprised of females having one offspring and on several occasions, sub-adult males and females were also seen but in ever changing composition. This leads to the conclusion that the basic unit is of an adult female with her one immature offspring rather than an adult female with all of her immature offspring as evident by the regular moving in and out of sub-adults from the group.

The concept of extended family (Douglas-Hamilton, 1972) or joint family (Sukumar, 1985) was not evident during the present study as majority of female groups (n = 456 or 83%) were mixed comprising of adult male(s), females, sub-adults and juveniles. An extended or joint family should necessarily be comprised of related individuals. The presence of males in groups does not confirm the assertion of the above concept. If the accompanying male(s) is/are considered as one of the offspring of the constituent mother of the group then the question is what purpose the male(s) serve in the group. The presence of males in female groups can only be for breeding as male elephant cannot recognize its offspring and therefore, do not participate in taking care of young ones. In such a circumstance, association of a male with its own family would not be an adaptive strategy, as it would lead to inbreeding. Sukumar (1985) has rightly opined that "males leave their families after puberty, a strategy that may be adaptive in avoiding the deleterious consequences of inbreeding". This leads to the conclusion that males attached to a female group are not related to the same family. The perusal of data obtained after regular monitoring of two female groups (RFG & CFG) revealed that the group size and composition was so dynamic that it was ever changing barring at a few occasions when the group composition remained the same for few days. If the large groups are formed by the related family units, then the group composition and size must show some predictable pattern because splitting and joining of family units would either reduce or increase group size in a fixed numbers. These evidences are enough to reject the concept of joint family. This leads to another question as to why elephants form groups larger than the basic unit. The primary function of group formation among animals seems to be the protection and care of young ones and development of behaviour, which can be regarded as manifestation of natural selection if viewed from the evolutionary perspective. It is well evident that at times of danger either due to the presence of a predator or for any other reasons female elephants form protective ring around calves and the matriarch takes the responsibility to ward off the danger by showing aggressive behaviour. Secondly, elephants are known to occupy large areas as their home ranges and move regularly between seasonal ranges to provide enough time for vegetation to rejuvenate in order to minimize the ill effects of over utilization, thus ensuring regular supply of food in future. In such circumstances, moving in groups is beneficial, as it would serve dual purpose; better care of young ones and development of behaviour among juveniles about the ways to exploit food resources in a sustainable manner. As far as the protection, care of young ones and development of behaviour among the progeny are concerned, relatedness of adult individuals probably is of little importance, as these amounts to better survival strategy and fitness of individuals rather than a group or population.

7.5 Summary and conclusions

Asian elephants in the Rajaji National Park form small groups. The majority of groups are comprised of up to 15 individuals and the mean group size of female groups ranges between 7.66 and 8.37. The mean group size does seem to be influenced only by the availability of water as during summer comparatively larger groups were observed. Other parameters, such as season, vegetation type and terrain types, do not influence the group size. The adult males usually remain solitary but some time form small groups up to 7 individuals, however, the association between the individuals is just by chance encounters. Majority of female groups accompany male(s) but the males do not show any fidelity towards a particular female group. The stable relationship is between a female and her one offspring usually either a small or a large calf and can be regarded as family unit. All other associations either between individuals of cow-calf groups, male-female groups or mixed groups are due to chance encounters and do not show any definite pattern that can explain certain relationship.

Table 7.1 Mean group size, standard deviation and number of groups of elephants in Rajaji National Park during different seasons.

	Winter	Summer	Monsoon	Overall
Mean group size	7.8	8.37	7.66	7.96
Standard deviation	5.23	6.05	4.26	5.38
No. of groups	210	168	76	454

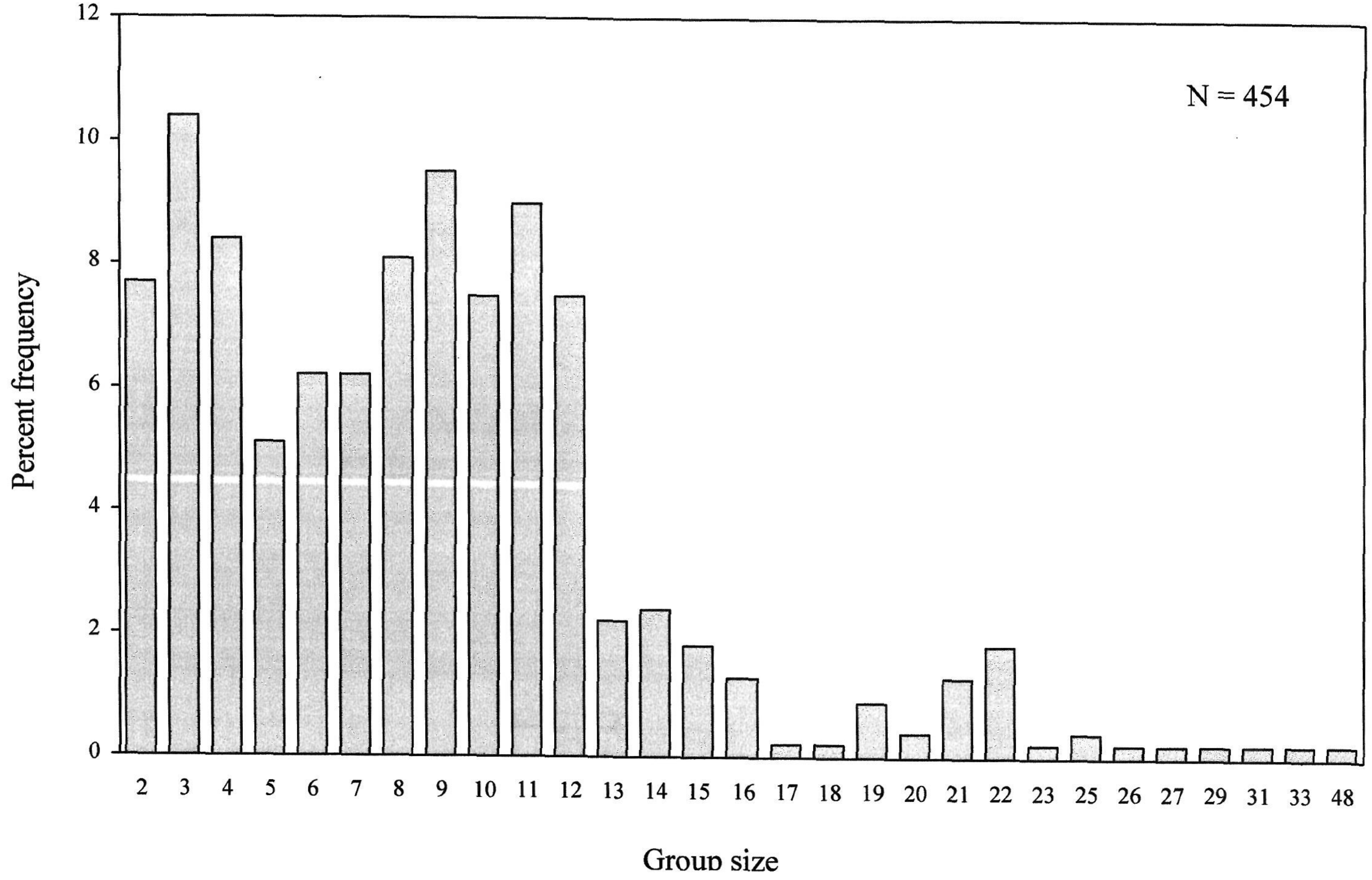


Fig. 7.1 Percent sighting frequencies of elephant groups in different group sizes in Rajaji National Park.

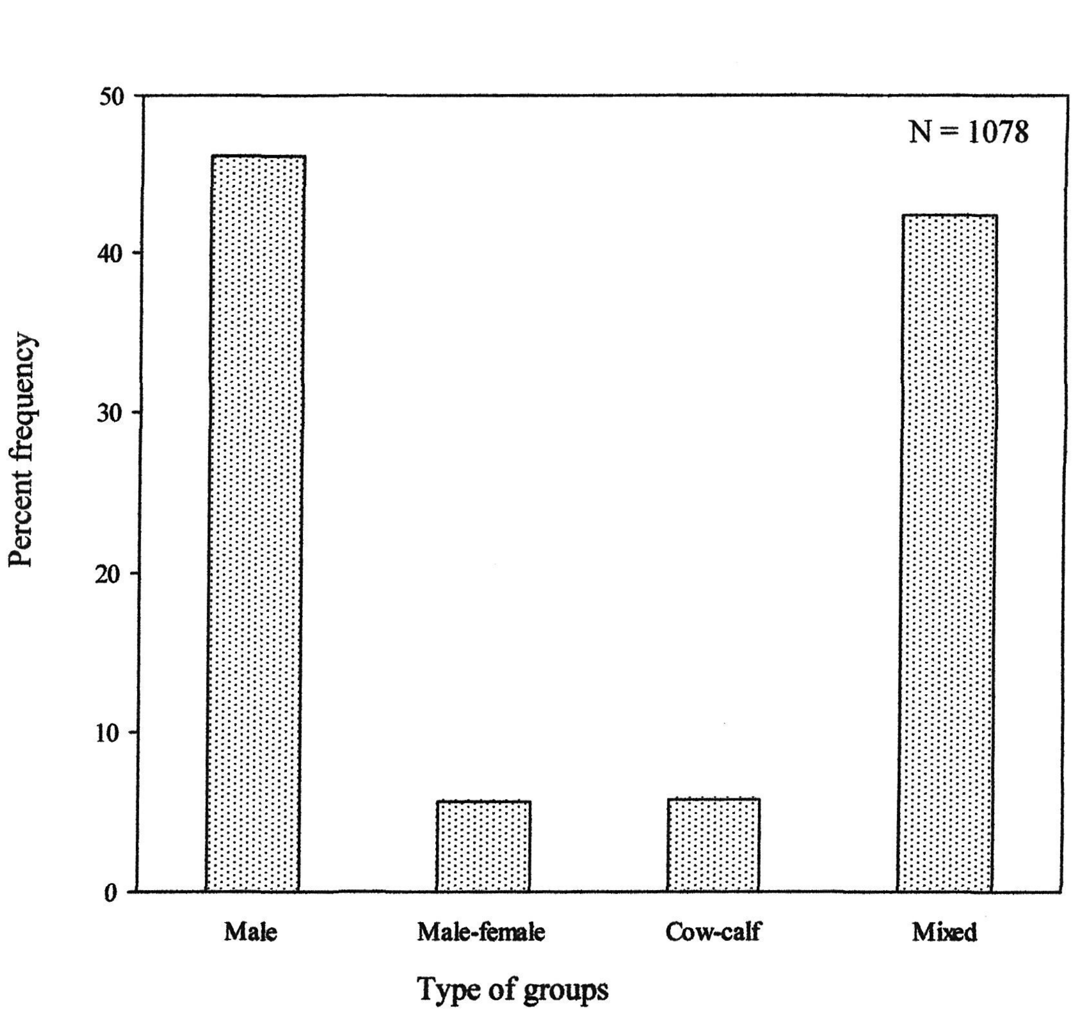


Fig. 7.2 Percent sighting frequencies of elephant groups in Rajaji National Park.

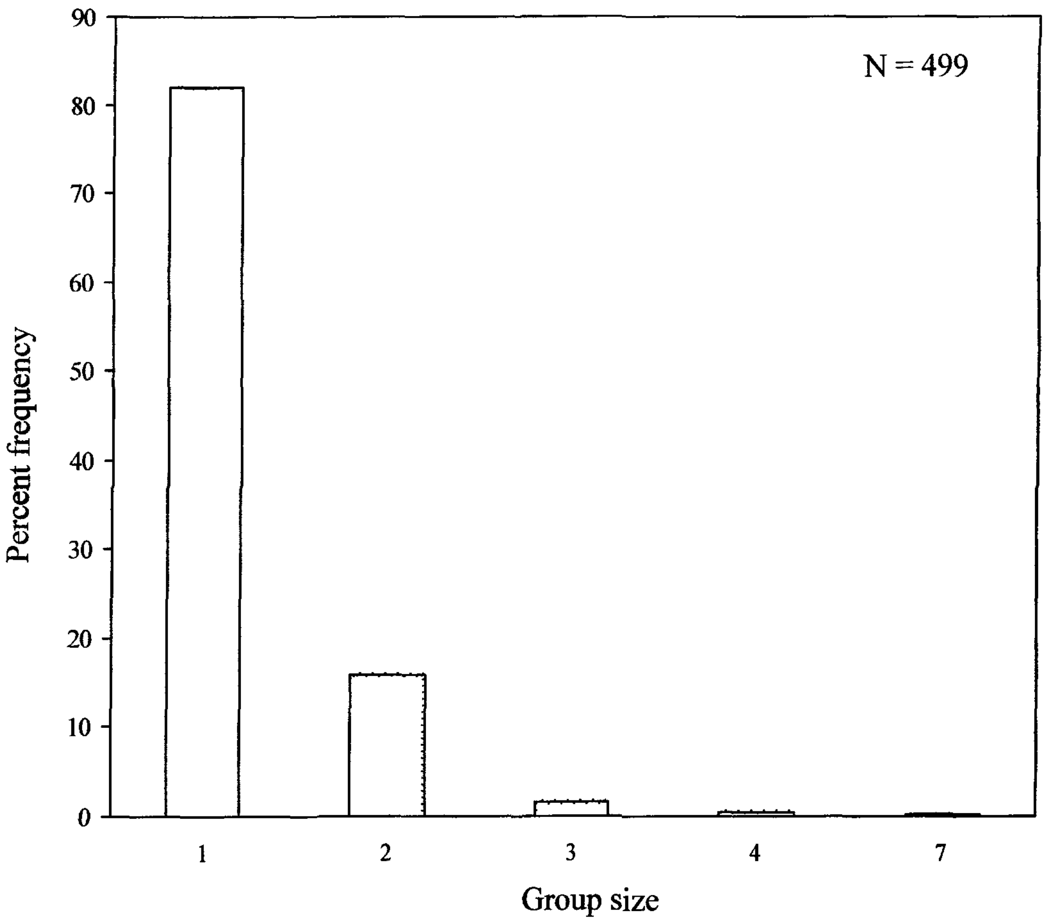


Fig. 7.3 Percent sighting frequencies of male elephant groups in Rajaji National Park.

Table 7.2 Seasonal sighting frequencies and their percentage of male groups in Rajaji National Park.

Group size	Frequency of sightings							
	Winter		Summer		Monsoon		Overall	
	N	%	N	%	N	%	N	%
1	144	84.2	137	84.6	128	77.1	409	82.0
2	25	14.6	22	13.6	32	19.3	79	15.8
3	02	1.2	1	0.6	5	3.0	8	1.6
4	Nil	Nil	2	1.2	Nil	Nil	2	0 .4
7	Nil	Nil	Nil	Nil	1	0.6	1	0 .2
Total	171	100	162	100	166	100	499	100

Table 7.3 Seasonal and overall mean groups size, standard deviation (SD) and minimum, maximum (Min-Max) number of elephants among different categories of groups in Rajaji National Park.

	Winter			**Summer**			**Monsoon**			**Overall**	
Group structure	Mean group size	SD	Min-Max	Mean group size	SD	Min-Max	Mean group size	SD	Min-Max	Mean group size	SD
Male group	1.17	0.41	1 - 3	1.19	0.49	1 - 4	1.29	0.67	1 - 7	1.21	0.53
Male-female group	5.75	4.12	2 - 17	2.95	1.81	2 - 8	3.08	0.74	2 - 5	3.74	2.63
Cow-calf group	2.87	1.26	2 - 7	3.44	1.92	2 - 8	4.67	1.60	3 - 7	3.16	1.54
Mixed group	9.88	5.83	3 - 36	10.78	6.45	3 - 52	8.74	4.24	3 - 24	9.97	5.82

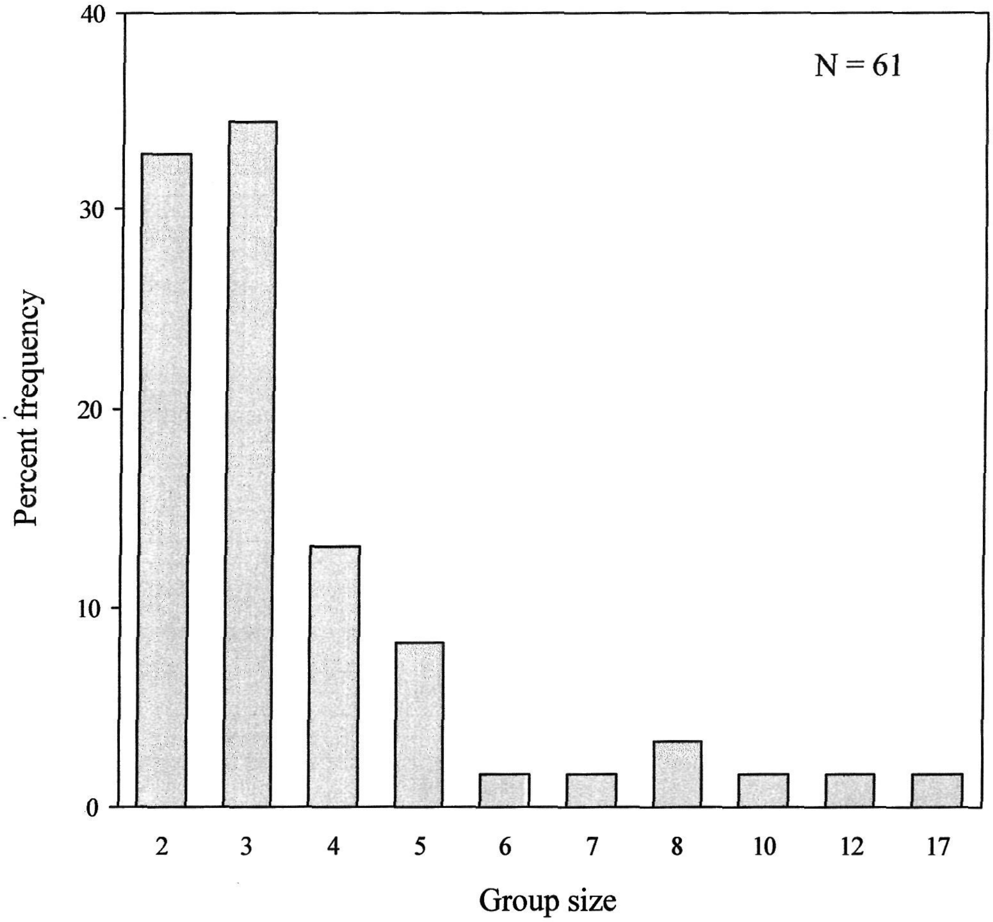


Fig. 7.4 Percent sighting frequencies of male-female groups in Rajaji National Park.

Table 7.4 Seasonal sighting frequencies and their percentage of male-female groups in Rajaji National Park.

Group size	Frequency of sighting							
	Winter		Summer		Monsoon		Overall	
	N	%	N	%	N	%	N	%
2	2	12.5	13	68.4	5	19.2	20	32.8
3	4	25.0	2	10.5	15	57.7	21	34.4
4	2	12.5	1	5.3	5	19.2	8	13.1
5	3	18.3	1	5.3	1	3.8	5	8.2
6	1	6.3	Nil	Nil	Nil	Nil	1	1.6
7	Nil	Nil	1	5.3	Nil	Nil	1	1.6
8	1	6.3	1	5.3	Nil	Nil	2	3.3
10	1	6.3	Nil	Nil	Nil	Nil	1	1.6
12	1	6.3	Nil	Nil	Nil	Nil	1	1.6
17	1	6.3	Nil	Nil	Nil	Nil	1	1.6
Total	16	100	19	100	26	100	61	100

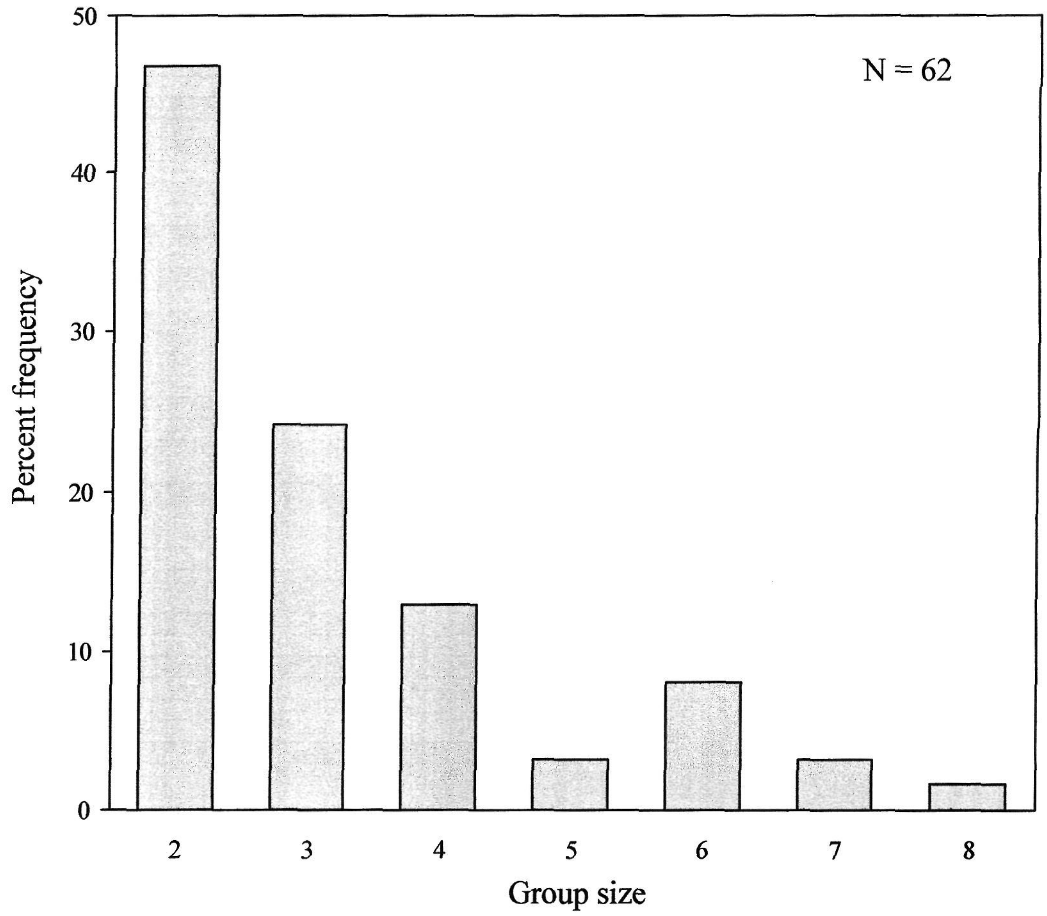


Fig. 7.5 Percent sighting frequencies of cow-calf groups in Rajaji National Park.

Table 7.5 Seasonal sighting frequencies and their percentage of cow-calf groups in Rajaji National Park.

Group size	Frequency of sighting							
	Winter		Summer		Monsoon		Overall	
	N	%	N	%	N	%	N	%
2	21	53.8	9	50.0	Nil	Nil	29	47.6
3	9	23.1	3	16.7	3	50.0	15	23.8
4	6	15.45	1	5.6	1	16.7	8	12.7
5	Nil	Nil	1	5.6	1	16.7	2	3.2
6	2	6.3	3	16.7	Nil	Nil	5	7.9
7	1	6.3	Nil	Nil	1	16.7	2	3.2
8	Nil	Nil	1	5.6	Nil	Nil	1	1.6
Total	39	100	18	100	6	100	62	100

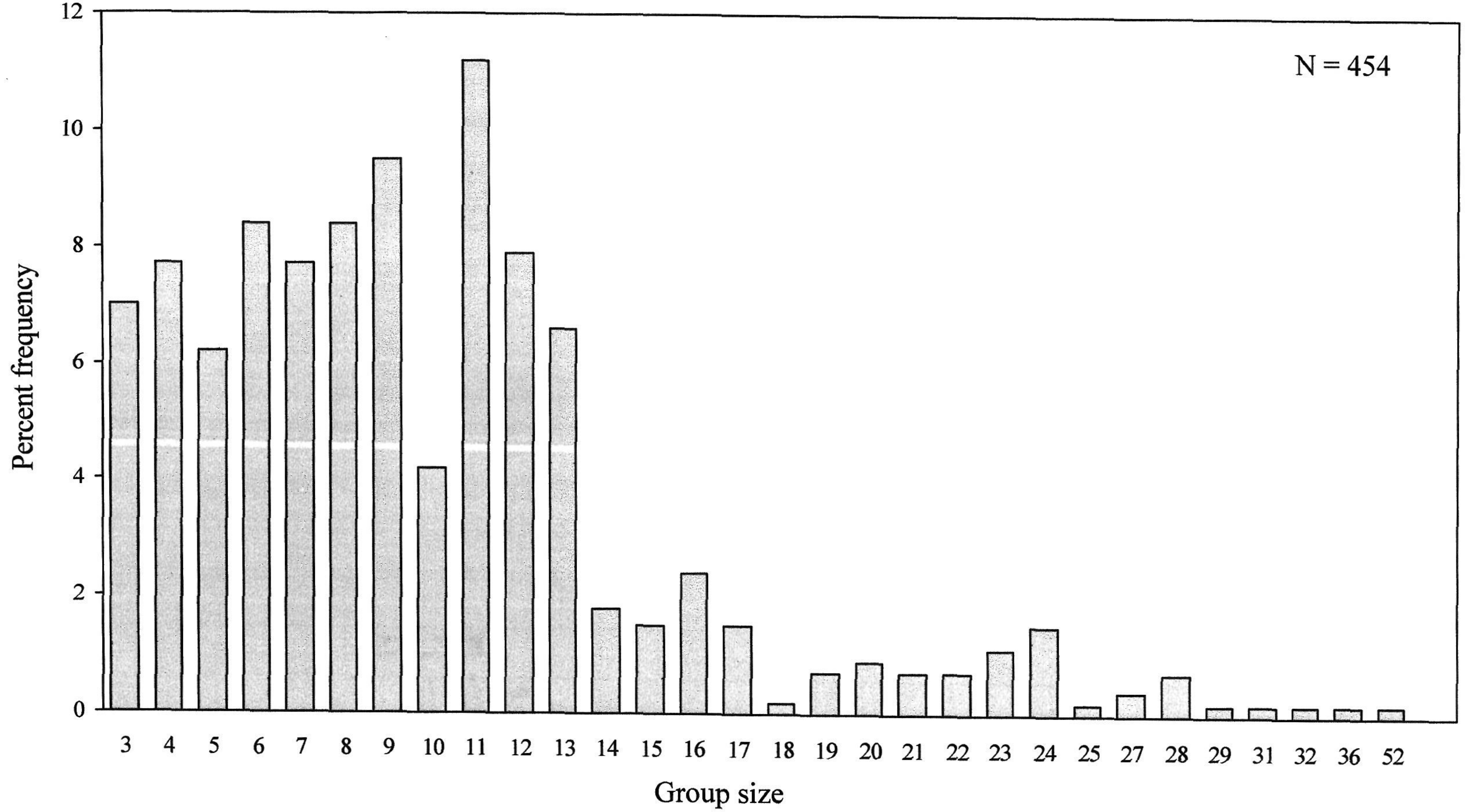


Fig. 7.6 Percent sighting frequencies of mixed groups in Rajaji National Park.

Table 7.6 Seasonal sighting frequencies and their percentage of mixed groups in Rajaji National Park.

Group size	Frequency of sighting							
	Winter		Summer		Monsoon		Overall	
	N	%	N	%	N	%	N	%
3	10	4.8	13	8.3	9	10.1	32	7.0
4	21	10.0	8	5.1	6	6.7	35	7.7
5	17	8.1	6	3.8	5	5.6	28	6.2
6	17	8.1	11	7.1	10	11.2	38	8.4
7	22	10.5	7	4.5	6	6.7	35	7.7
8	12	5.7	14	9.0	12	13.5	38	8.4
9	22	10.5	12	7.7	9	10.1	43	9.5
10	7	3.3	11	7.1	1	1.1	19	4.2
11	22	10.5	21	13.5	8	9.0	51	11.2
12	15	7.1	13	8.3	8	9.0	36	7.9
13	9	4.3	11	7.1	10	11.2	30	6.6
14	5	2.4	3	1.9	Nil	Nil	8	1.8
15	3	1.4	4	2.6	Nil	Nil	7	1.5
16	9	4.3	2	1.3	Nil	Nil	11	2.4
17	1	0.5	3	1.9	3	3.4	7	1.5
18	Nil	Nil	1	0.6	Nil	Nil	1	0.2
19	2	1.0	1	0.6	Nil	Nil	3	0.7
20	2	1.0	2	1.3	Nil	Nil	4	0.9
21	2	1.0	1	0.6	Nil	Nil	3	0.7
22	2	1.0	1	0.6	Nil	Nil	3	0.7
23	2	1.0	3	1.9	Nil	Nil	5	1.1
24	2	1.0	3	1.9	2	2.2	7	1.5
25	Nil	Nil	1	0.6	Nil	Nil	1	0.2

27	**1**	0.5	**1**	**0.6**	**Nil**	**Nil**	**2**	**0.4**
28	1	0.5	2	1.3	Nil	Nil	3	0.7
29	**1**	0.5	**Nil**	**Nil**	**Nil**	**Nil**	**1**	**0.2**
31	1	0.5	Nil	Nil	Nil	Nil	1	0.2
32	**1**	**0.5**	**Nil**	**Nil**	**Nil**	**Nil**	**1**	**0.2**
36	1	0.5	Nil	Nil	Nil	Nil	1	0.2
52	Nil	Nil	**1**	**0.6**	**Nil**	**Nil**	**1**	**0.2**
Total	210	100	156	100	98	100	454	100

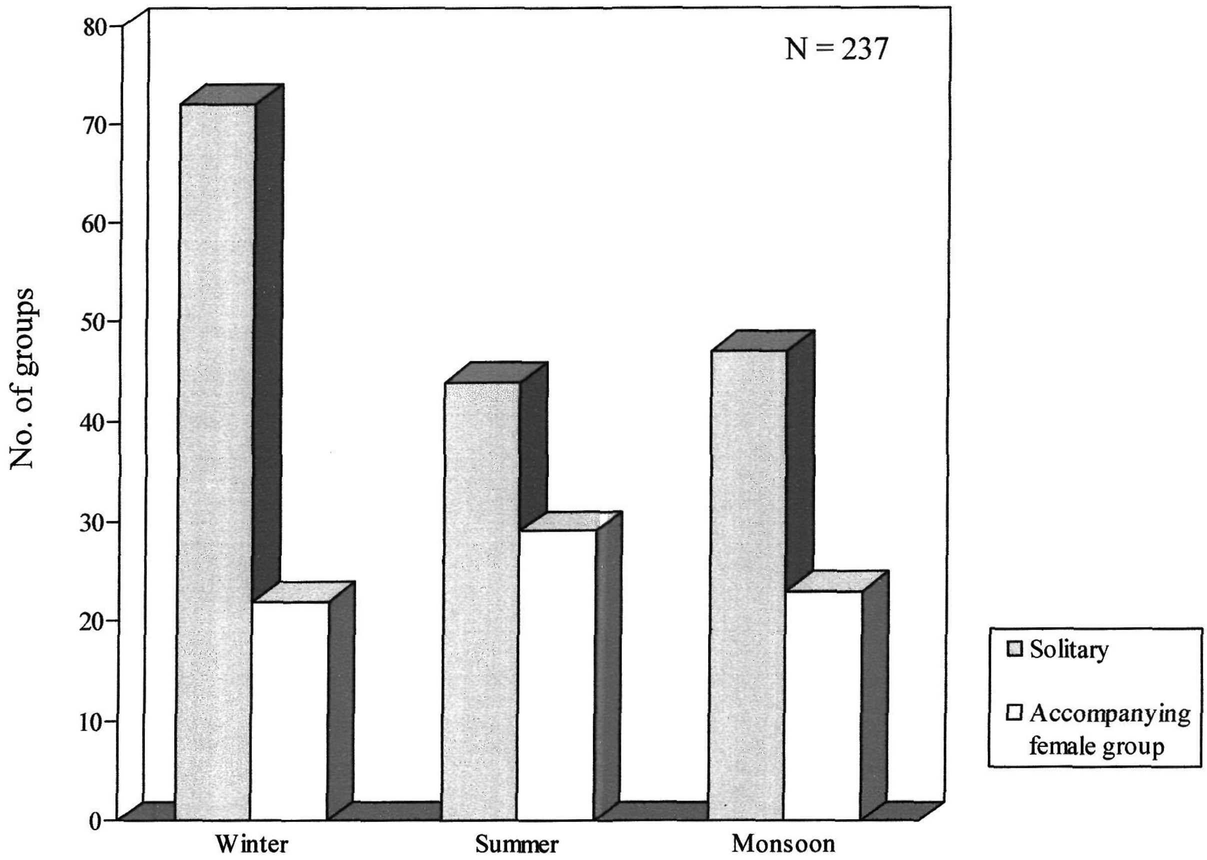


Fig. 7.7 Seasonal group structure of MR1 in Rajaji National Park.

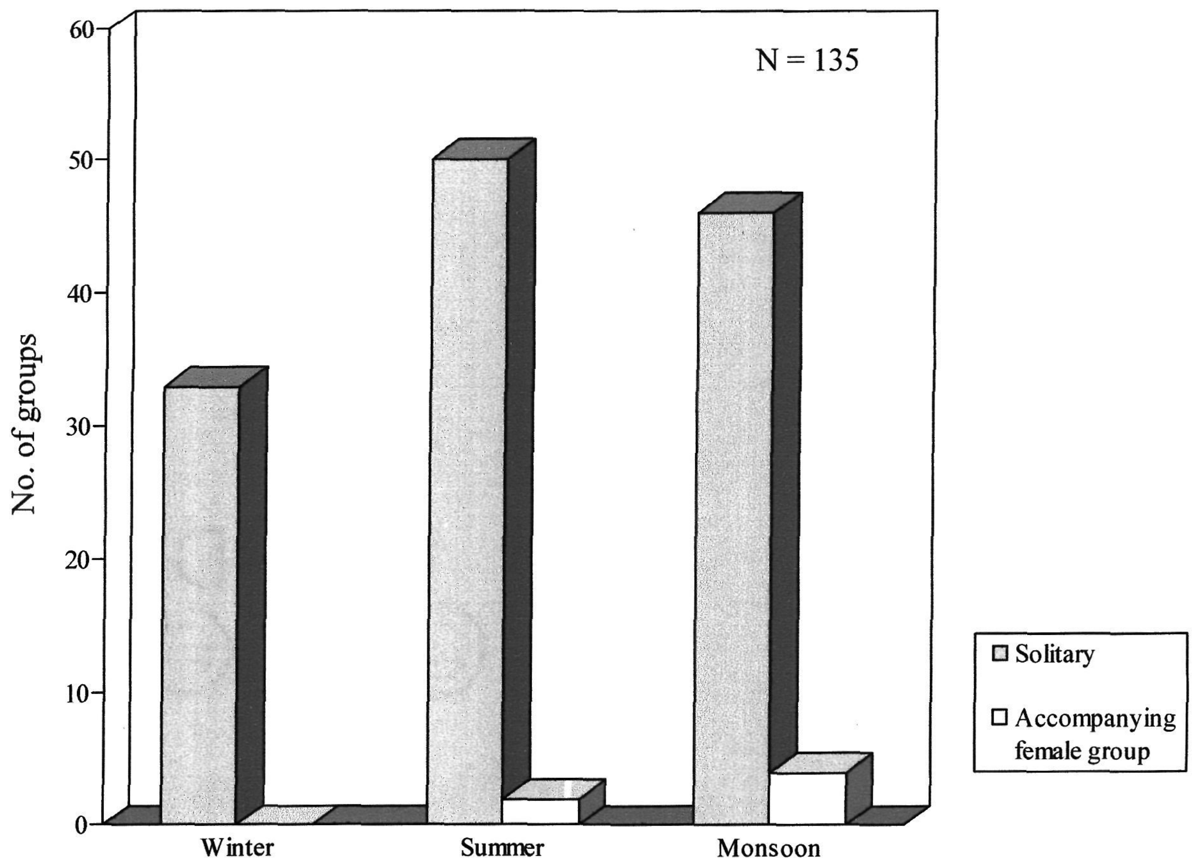


Fig. 7.8 Seasonal group structure of MR2 in Rajaji National Park.

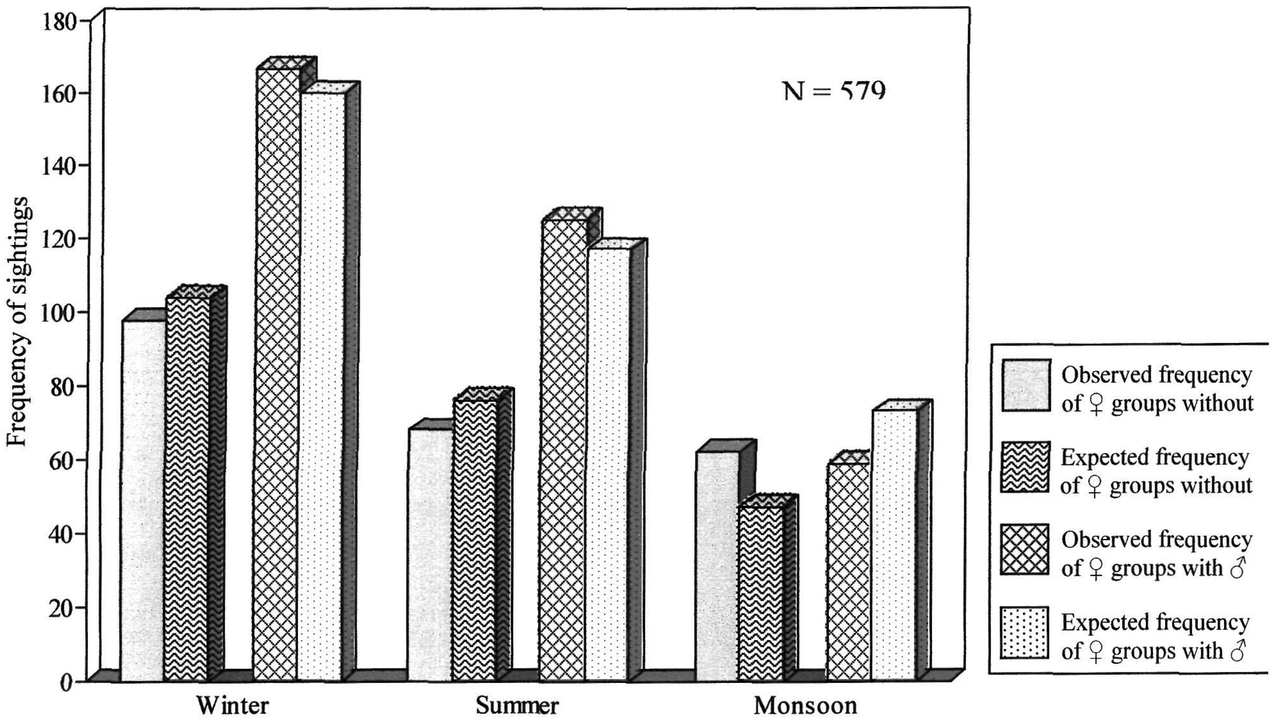


Fig. 7.9 Seasonal variation in observed and expected sighting frequencies of female groups with and without male(s) in Rajaji National Park.

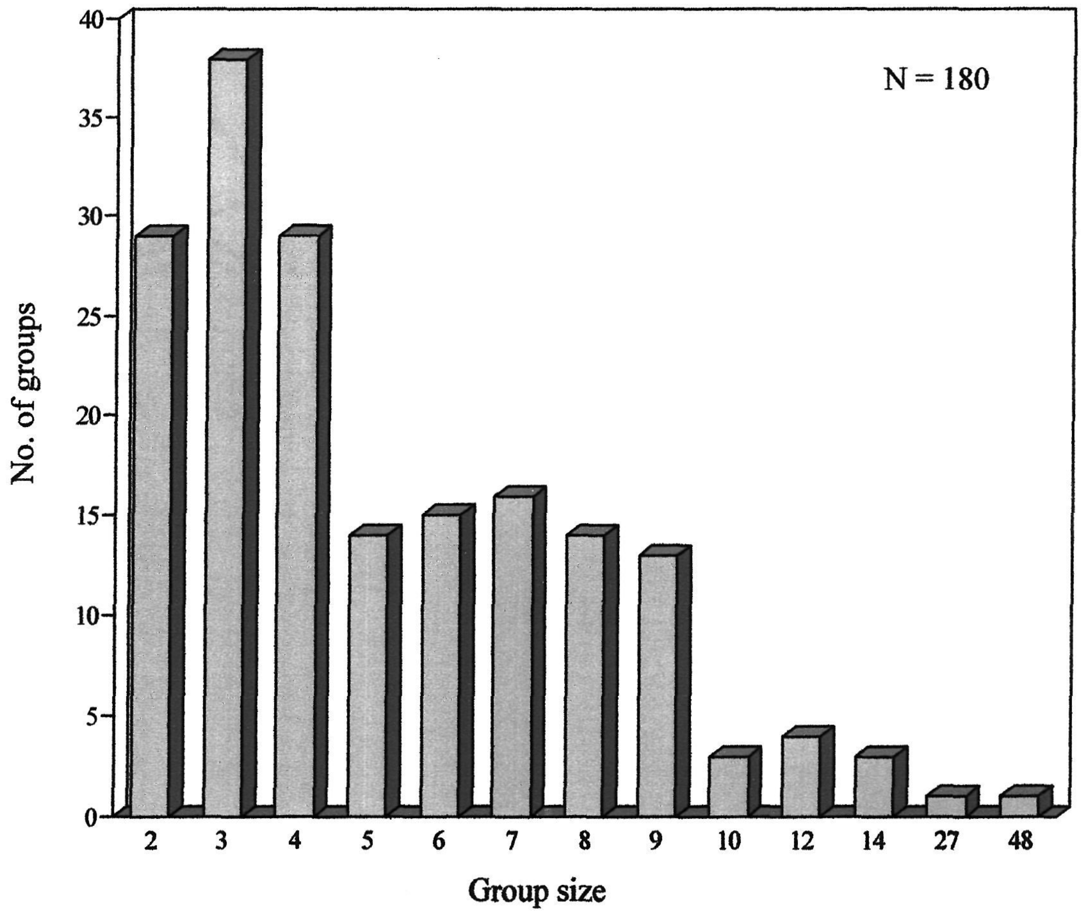


Fig. 7.10 Sighting frequencies of RFG (female group) among different group sizes in Rajaji National Park.

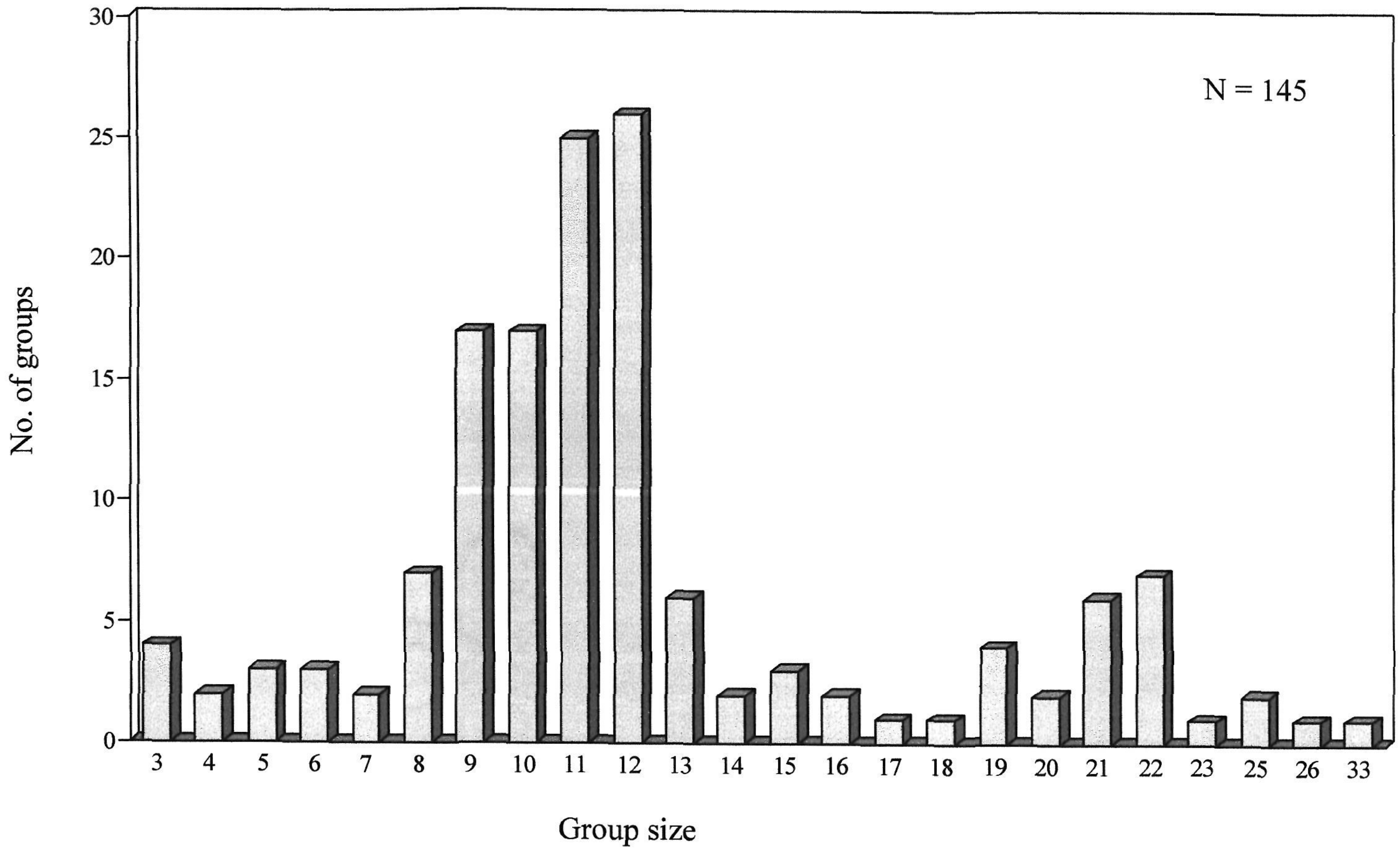


Fig. 7.11 Sighting frequencies of RFG (female group) among different group sizes in the Rajaji National Park.

Chapter 8: Conservation problems and management implications

8.1 Introduction

Elephant population in the northwest India is facing major conservation problem due to its fragmentation. A larger part of this population inhabits Rajaji and Corbett National Parks including the forest area between the two (Fig. 1.1 in Chapter 1). As has been described in Chapter 1 (Section 1.1) that this contiguous habitat is connected with narrow strips of forest at two places, between Rajaji-Motichur and Chilla Wildlife Sanctuaries and between Chilla WLS and Kalagarh Forest Division (hereafter referred as KEC). Considering the heavy biotic pressure on these narrow forest strips, which are serving as corridors for animal movements, it was presumed that elephant movements through these corridors have been stopped and hence this study was initiated to assess the status of these corridors along with other aspects of the elephant ecology in the region. It was therefore decided that at least 10 elephants would be radio-collared at two sites, five in Rajaji-Motichur area and another five at Chilla WLS and it was expected that the status of both corridors would be assessed along with other ecological parameters. However, due to some unavoidable circumstances, constraints of funding and infrastructure facilities, only four elephants could be radio-collared, three in Rajaji-Motichur unit and one in Chilla WLS and the scope of the study was reduced to Rajaji National Park only. However, considering the importance of the KEC and to have a complete picture of elephant conservation problems in the region, a short-term investigation was carried out to answer the questions such as:

1) Do elephants still use the KEC?
2) Is the KEC viable with present human pressure?
3) What would be the consequences for the northwest elephant population if the KEC was lost?

This chapter has two sections. In the first section, the results of the study on KEC have been reported and in the second section, conservation problems and management implications for Rajaji have been discussed.

8.2 Methodology

The study area was a belt of reserved forest starting from Rawasan River to Khoh River, which forms the KEC comprising of Laldhang and Kotdwar Forest Ranges of Lansdowne Forest Division (Fig 8.1). The KEC was divided into three sections based on the knowledge of elephant distribution and occupancy. The section I was between Rawasan and Malan rivers, section II included the area between Malan and Paniyali Forest Rest House and the section III was comprised of forest area between Paniyali FRH and northeast words up to Amsaur village (Fig 8.1).

A total of 22 belt transects (10 in section I, 7 in section II and 5 in section III) of 1 km length and 10 m width were laid to collect data. All transects were perpendicular to Laldhang-Kotdwar road and Kotdwar-Dogadda road, originating from a point 100 m away from the road in the forest (Fig. 8.1).

8.2.1 Field data collection and analysis

Data on vegetation structure was collected by enumerating all trees bearing 30 cm and more GBH within the 10 m wide belt transect. All trees were identified to the species and their numbers were recorded. Three circular plot of 2 m radius, one each at the beginning, middle and at the end of a transect were established to collect data on regeneration. Thus, a total of 51 plots were sampled. Data on regeneration of tree species were collected in each circular plot by enumerating saplings of various tree species. Forest condition in general in terms of diversity and abundance of elephant food plant species was determined by comparing densities of tree species and elephant food plant species with special reference to *Mallotus philippensis* and *Dendrocalamus strictus*.

The occurrence of elephant dung and damage to vegetation were recorded as an indicator of elephant movement and utilization in the various sections of the KEC. Notes on other evidences such as footprints and feeding trails were also made whenever observed. Elephant dung piles were enumerated on the belt transects. Feeding signs left by the elephants were recorded and each tree bearing feeding signs was identified as to species and nature of damage. The damage to the trees was classified into four different classes viz. crown breaking, pushing over, debarking and converted into shrub.

The number of cattle dung piles and number of trees lopped by the villagers were recorded at each transect as an indicator of human disturbance in the area. Apart from this, villagers, forest department personnel, bamboo cutters and cattle graziers were interviewed to understand the extent of human pressure and elephant movement between different sections of the KEC. One-way analysis of variance (ANOVA) was used to test the variations among sections whenever indicated.

8.3 Results

The results in the following sections are presented with an aim to compare three sections of the corridor in term of general vegetation characteristics, availability of elephant food plants, degree of human disturbance and elephant movements and occupancy.

8.3.1 Habitat condition

A total of 37 tree species were recorded in all three sections of the KEC of which 35 species were in section I, 18 and 16 in section II and section III respectively. The density of tree species was highest (274 ±82 trees/ha) in section I and lowest (94 ± 23 trees/ha) in section III (Table 8.1) and the variation in the tree densities among different sections was significant ($F_{2\ \&\ 27} = 11.8$, $P< 0.01$). The density of *Mallotus philippensis* was highest and it was followed by *Aegle marmelos*. Table 8.2 summarizes the details of density of different tree species in three sections.

The vegetation in section I was of miscellaneous type with patches of mixed plantations of *Ailanthus excelsa, Dalbergia sissoo* and *Acacia catechu*. There were few patches of *Tectona grandis* plantations. The forest in this area was young due to continuous silvicultural practices. There was a sparse distribution of *Haldina cordifolia, Anogeissus latifolia,* and *Dalbergia sissoo* in the upper canopy while the lower canopy was dominated by the *Mallotus philippensis, Aegle marmelos* and *Ehretia laevis*. *Shorea robusta* was predominant on gentler slopes.

Pure Patches of *Shorea* occurred in Section II. The upper canopy in this area was mainly composed of *Anogeissus latifolia, Edina cordifolia, Mitragyna parviflora* and *Holoptelea integrifolia*. The lower canopy was sparse and mainly consisted of *M. philippensis, Schleichera oleosa, Casearia elliptica* and *Cassia fistula*.

In section III, *S. robusta* was the predominant species and formed the upper canopy with *D. sissoo, A. latifolia, H. integrifolia*. The lower canopy was composed of *M. philippensis* and *C. fistula*. The tree canopy was more open and facilitated the growth of *Dendrocalamus strictus* (40 clumps/ha), which along with *Mallotus* made the northern half of section III.

The density of elephant food trees differed significantly among three sections ($F_{2 \& 27}$ = 9.0, P<0.01). The highest number and density of food tree species were recorded in section I and much lower in section II and III (Table 8.1). Monoculture plantations and biotic interference has reduced the density of food trees to 57 trees / ha in section II.

Regeneration of seven tree species was recorded and saplings of *M. philippensis, E. laevis* and *E. marmelos* all elephant food trees were present in section I and section III. The density of *M. philippensis* was highest in the southern portion of section II. A relatively higher density of *S. robusta* saplings was recorded in section II and III (Table 8.3).

8.3.2 Elephant occupancy

Elephant damage to trees and elephant dung pile both were recorded in all sections of the KEC. The damage caused by elephants was significantly different among three sections ($F_{2 \& 16}$ = 13.6, P< 0.01) and it was highest in section I as compared to other sections (Table 8.4). The damage caused to the trees by elephants in all three ways viz. crown breaking, pushing over and converted into shrub was also highest in section I and lowest in section II (Table 8.4). Similarly, the densities of elephant dung piles were highest in section I and lowest in section II (Fig. 8.2).

8.3.3 Biotic pressures

Apart from the silviculture practices, other major factor, which reflects upon the forest and its condition, is the quantum of human pressure on it. The only visible signs of biotic pressures in the corridor area were lopping and cattle grazing. The lopping pressure was highest in section II while it was relatively low in other two sections (Fig. 8.3). There were significant differences in the extent of tree lopping between three sections ($F_{2 \& 16} = 21.1$, $P<0.01$). It is worth mentioning that there was lopping of *M. philippensis* in section II despite the fact that *Mallotus* is not considered as cattle food elsewhere in the region and not at all lopped though it occurred all over the region in good numbers. This indicates the extent of lopping being done here.

Cattle normally use fixed tracks along the rivers/rivulets. A straight line transect inside the forest hence greatly underestimates the cattle dung pile density as against the presence of about 10,000 of cattle head registered for grazing in the KEC. The rights and concessions for lopping, grazing and wood collection appeared to be concentrated in eastern half of the section II. A total of 140 villages having more than 12,000 cattle heads are indicative of the severity of pressure.

8.4 Discussion

The overall tree density in the KEC forest is very low as compared to nearby Rajaji (Chapter 4). The reasons for low tree density are removal of mature trees as a part of siviculatural practice as followed by the Forest Department, heavy lopping pressure and cattle grazing. However, the forest stands did not appear degraded due to good growth of understory trees most of which have not yet attained a GBH of 30 cm or above and hence were not considered as mature trees while sampling was carried out.

The overall low generation in section I was mainly due to the loss of natural vegetation, which has been replaced by the mixed or monoculture plantations. The terrain of section I is not as rugged as it is in other two sections and therefore level of extraction of trees by the forest department under the silvicultural operations were much higher due to easy operations in easy terrain.

The data on damage to the trees by elephants and density of elephant dung piles (both indicative of elephant usage) were higher in section I and III. However, further analysis of the data suggested that most damage to trees was in the second half of the transects about 600-700 m from the periphery of the forest. The reluctance of elephant groups to come to the southern part of section II is due to the higher degree of human disturbance. However, lone bulls do frequently visited this area while small female groups were occasionally seen as confirmed through the interviews.

Earlier the view was held that elephants do not move through KEC mainly due to the rugged terrain at least at two places, along the rivers Malan and Khoh. Considering this, (H.S. Panwar, pers.comm.) had even suggested bulldozing of some area along the sides of both the rivers as a management option in order to facilitate barrier free movements of elephants through the corridor. However, during the study, there were enough evidences, which lead to the conclusion that rugged terrain is not a barrier for elephants to move through the KEC. For instance, a group of 10 elephants had crossed over the river Khoh and entered Kolhochaur forest (Fig 8.1) a few days before my visit to the area where it destroyed about hundred bundles of freshly cut bamboos. A walk along the banks of both rivers Malan and Khoh revealed that elephants regularly moved in the area as indicated by the presence of fresh and old elephant dung piles. The presence of elephants were also confirmed in section II and at both sides of the river Malan as the villagers reported incidences of crop raiding by elephants near Kalaghati and Kanav Ashram (Fig. 8.1).

If I once again analyze the overall picture of a larger part of Northwest Indian elephant population inhabiting forest tracts between Rajaji and Corbett National Parks then it emerges that this population of about 900 elephants is divided into three units based on the available area and habitat occupancy patterns. The Rajaji-Motichur unit has an area of 550 km² and about 150 elephants, Chilla unit has an area of 351 km² and about 300 elephants while the Corbett unit including Lansdowne FD and Ramnagar FD has an area 1400 km² and 400 elephants. It is clear that elephants of Rajaji-Motichur unit have an option of moving into near by Shivalik and Dehradun Forest Divisions. In fact, the elephants have already started moving in to the Shivalik FD as has already been established studying their movement pattern (Chapter 5, section 5.3.4). Since the corridor between Rajaji-Motichur and Chilla units seems to be a lost one as far as movement of elephant groups is concerned, the KEC assume greater significance. In case the KEC is lost, the Chilla elephant population (about 300) would be the largest population confined to a smallest isthmus of 350 km² in the region. In such a situation, it would not be wrong to predict that events in Chilla unit in due course of time will render the entire elephant population inhabiting Rajaji to Corbett National Park vulnerable to genetic as well as demographic stochasticity.

8.5 Summary and conclusions

The belt of reserved forest between Rawasan and Saneh rivers form the corridor between Chilla and Kalagarh Forest Division, which is contiguous with Corbett NP. Of importance, within the corridor is the area between Malan and Khoh rivers (section II). The forest within corridor area is degraded as evident by low densities of tree species. There are pockets within the corridor especially in section II where the biotic pressures are concentrating and as a consequence of it elephant movement and utilization in such areas is adversely affected. Given proper protection and management of biotic pressures, the habitat can recover from its present state, which in tern would facilitate frequent elephant movements through the corridor.

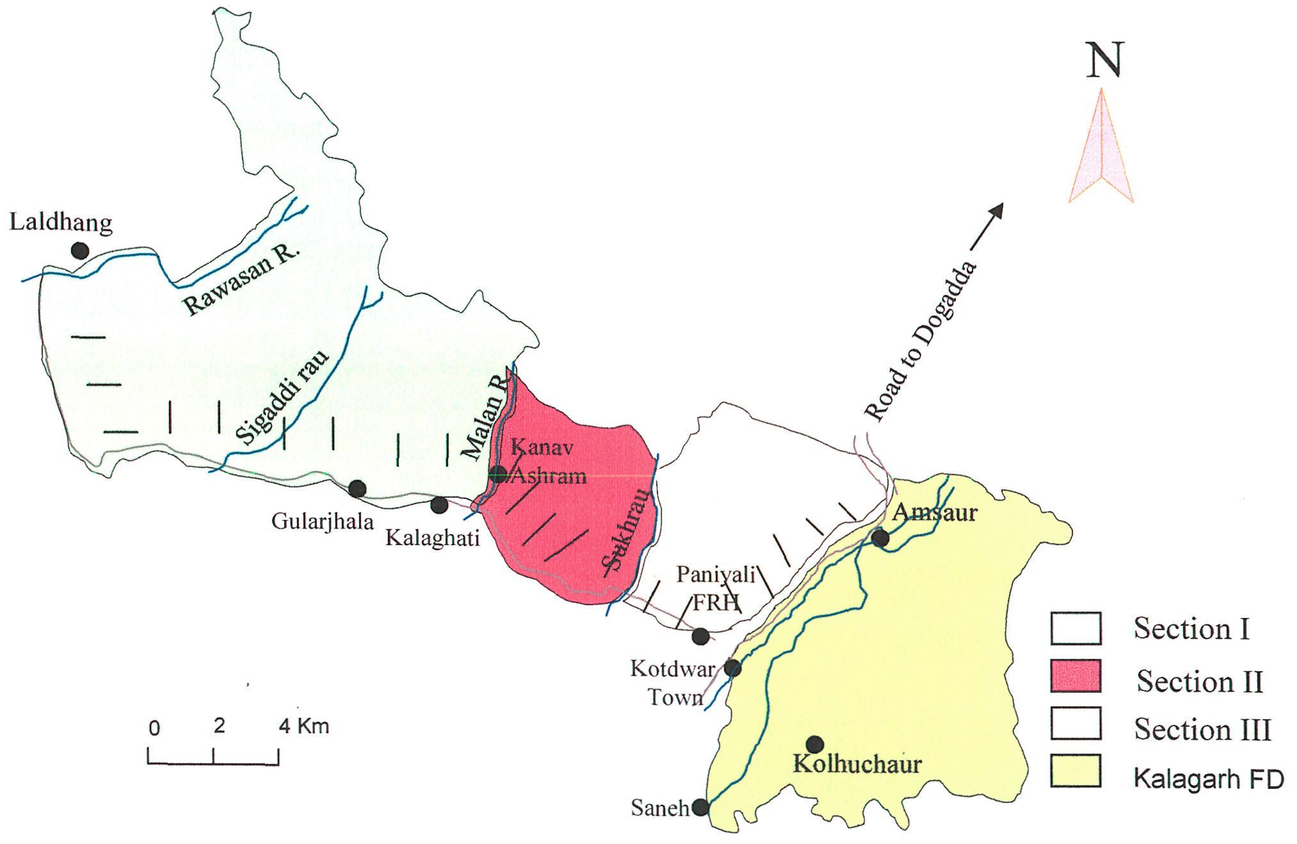


Fig. 8.1 Map showing different sections of KEC

Table 8.1 Number of tree species, elephant food plant species and their densities in three sections of KEC.

Sections	No. of tree species	Trees/ ha	No. of food tree species	Food trees/ha
Section I	35	274 ± 82	12	186 ± 75
Section II	18	136 ± 58	11	57 ± 28
Section III	16	94 ± 23	12	51 ± 34

Table 8.2 Density of trees in different sections of KEC.

Plant species	No. of trees per ha		
	Section I	Section II	Section III
Acacia catechu	8	Nil	5
Aegle marmelos	50	2	5
Ailanthus excelsa	14	Nil	Nil
Albizia lebbeck	1	2	3
Albizia procera	1	Nil	Nil
Anogeissus latifolia	5	11	10
Bauhinia sp.	2	Nil	2
Bombax ceiba	1	Nil	Nil
Casearia elliptica	1	8	
Cassia fistula	12	8	5
Cordia dichotoma	6	Nil	Nil
Dalbergia sissoo	5	Nil	9
Dendrocalamus strictus	Nil	Nil	40
Ehretia laevis	13	Nil	5
Emblica officinalis	Nil	4	2
Ficus benghalensis	1	Nil	Nil
Ficus religiosa	1	1	Nil
Flacourtia indica	1	3	Nil
Haldina cordifolia	2	11	Nil
Heplophragma	6	Nil	Nil
Holarrhena pubescens	13	Nil	Nil
Holoptelea integrifolia	6	10	6
Lagerstroemia parviflora	6	1	Nil
Lannea coromandelica	1	3	
Mallotus philippensis	81	27	12

Hymenodictyon orixense	1	Nil	Nil
Miliusa velutina	1	Nil	Nil
Mitragyna parviflora	5	4	2
Ougeinia oogeinsis	1	Nil	5
Schleichera oleosa	7	19	Nil
Shorea robusta	3	11	25
Tectona grandis	4	Nil	Nil
Terminalia alata	3	4	Nil
Terminalia bellirica	5	2	4
Trivia nudiflora	1	Nil	Nil
Ziziphus mauritiana	6	Nil	Nil
Ziziphus xylopyra	1	Nil	Nil

Table 8.3 Density of saplings among different sections of KEC.

Plant species	No. of saplings per ha		
	Section I	**Section II**	**Section III**
Aegle marmelos	372	Nil	53
Albizia lebbeck	Nil	80	213
Cassia fistula	Nil	199	318
Ehretia laevis	79	Nil	106
Holarrhena pubescence	239	Nil	Nil
Schleichera oleosa	26	159	Nil
Mallotus philippensis	1380	2768	1751
Shorea robusta	Nil	3662	4246
Total	**2096**	**6886**	**6687**

Table 8.4 Number and percent of trees damaged by elephants in different damage categories among three sections of KEC.

Sections	No. of total food trees	Total damaged	% damage	Browsed		Converted into shrub		Pushed over	
				No. of trees	percent	No. of trees	percent	No. of trees	percent
Section I	1860	822	44.1	322	17.3	399	21.4	101	5.3
Section II	398	78	19.5	36	9.0	24	6.0	18	4.5
Section III	256	66	25.7	32	12.5	18	7.0	16	6.2

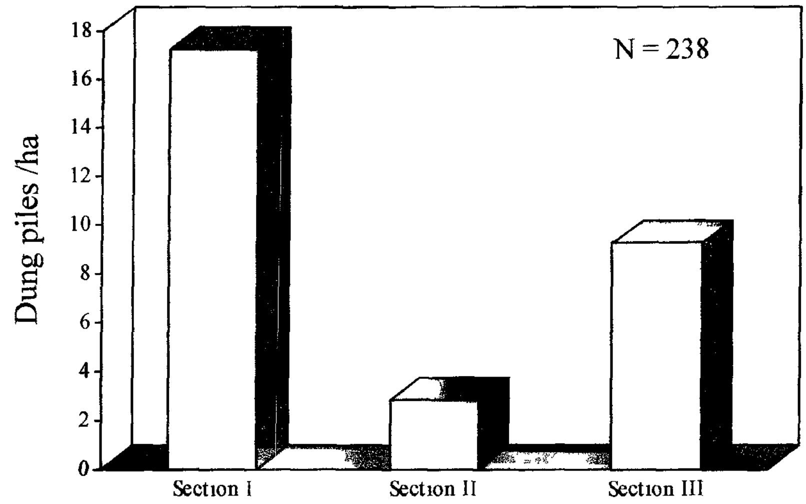


Fig. 8.2 Density of elephant dung piles in different sections of KEC.

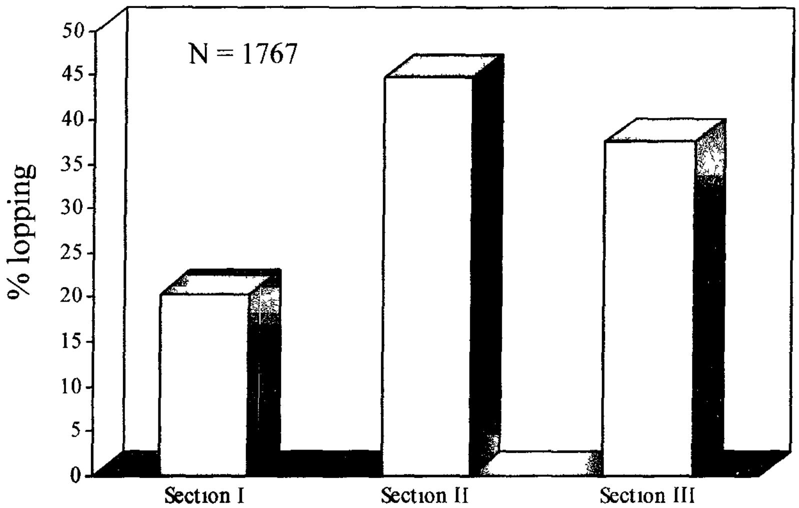


Fig. 8.3 Percentage of trees lopped in different sections of KEC.

8.6 Management implications

The results of present study on elephant ecology and its habitat is expected to provide some feedback to the managers and the same can be utilized them in designing a sound management strategy for conservation of elephants and their habitats in Rajaji. The following sections are based on the results of the study and experience gained during the stay in Rajaji while carrying out fieldwork. Whatever described in this chapter is the opinion of the author and opens for debate if required.

8.6.1 Past management practices and their impact

Before declaration of this area as Rajaji National Park it was part of the Shivalik, Dehradun East and Lansdowne Forest Divisions conventionally designated as "reserved forests" during the British period and these forests served as the repository of game and timber. The management at that time was mainly centred around activities such as timer harvest for economic gains, raising plantations and management of game allowing public to shoot wild animals. Apart from this, villages in and around the forest had been given concessions and rights on some of to meet their requirements of timber, grasses for construction of hutments and fodder for their cattle. These rights and concessions were in the form of cattle grazing, limited extraction of timber, grasses etc and in turn the villagers used to help in management activities such as raising plantations, enforcement of forest laws and fire fighting. These practices continued well after the independence. However, the enactment of Wildlife (Protection) Act, 1972 put a complete ban on hunting of wild animals. The extraction of timber, minor forest produces (MFP) and plantations, however continued until the area was declared as National Park in 1984. In pursuance of norms of a national park, there was a shift in management orientation from commercial exploitation to complete protection of forest resources, suspension of traditional rights and concessions to locals and exclusion of human habitations from the Park. In this process, all villages within the boundary of the Rajaji National Park were shifted out or the realignment of boundary was done in order to exclude the villages. The efforts were made to shift out a transhumant pastoralist tribe –the Gujjar those were traditionally living in Rajaji.

The analysis of past practices and its impacts on the Rajaji ecosystem reveals that there are both positive effects and negative impacts. Plantations of exotic species have certainly created an adverse impact on the ecosystem. Such patches are largely devoid of regeneration of natural species, weeds have dominated the understory and these areas in today's context serve no purpose. Contrary to that, gap filling plantations of native species have produced encouraging results. Such areas have more floral diversity and density of trees and shrubs as compared to homogenous stands of natural vegetation such as Sal forests. From the perspective of elephants, patches where gap filling plantations of elephant food plant species have been carried out, seems to be an attractant to elephants. The use of bamboo plantation patches towards the southern boundary of Rajaji WLS by elephants during monsoon illustrates this.

Shifting out of villages from the National Park can be viewed as a positive step as the continued increase in human population and advancement of the human society would have caused reduction and further fragmentation of elephant habitat. However, suspension of traditional rights and concessions has brought no respite to local people. The people have been alienated from the management and a sense of belongingness to the forest has been lost. Now the villagers are antagonized and do not help management in times of crisis such as fire fighting operations and protection of forest resources. This has lead to increased hostility towards the wild animals as well. The traditionally forest dependent communities living in villages still use forest resources though illegally and magnitude of exploitation has now increased from their own use to commercial. As a consequence of this, the task of forest personnel has become difficult as their maximum time is spent on protection, leaving little for other management activities. Considering this, the government has now decided to include villagers as a partner in conservation and management of forests and a model has been developed in which villagers were empowered through formation of village forest committees who would work in conjunction with forest department officials. The result of such an effort has yet to demonstrate its utility. However, considering the social fabric of India and analysis of the model, it seems that it would bring more harm than the harmony. A full-length discussion here on this subject would not be appropriate and therefore I have restricted myself to express my views after the analysis of the present model on people participation in forest/wildlife management.

The efforts of the Forest Department to shift Gujjar out side the Rajaji National Park have also resulted in "chaos". The Gujjar, who used to move between Rajaji and other parts of the Himalayan hills seasonally (see chapter 2, section 2.11), fearing the denial to Rajaji resources, have discontinued transhumant pastoralist practices since 1984 and they are now permanent residents of Rajaji. As a result of this, the utilization of Rajaji resources by the Gujjar has increased by at least three folds. This has resulted in degradation of habitat in the form of spread of weeds and low regeneration of fodder trees due to continuous lopping. Considering the current political situation, it seems difficult to arrive at an amicable solution to the Gujjar problem. If the present practices continued, it will not be wrong to say that in due course of time Rajaji habitat would no longer be suitable to meet the requirements of elephant population, which is steadily growing.

8.6.2 Management implications for elephant habitat

The broad classification of the vegetation types seems to be appropriate from the management point of view as these are easily recognizable in the field and not much knowledge of plant ecology would be required. The results on the species diversity, richness, density, weed abundance etc have been provided block wise which would act as a reference for comparison purposes in order to detect likely changes in the vegetation structure in future. Based on the data provided in chapter 4 on the habitat structure and composition the management can draw its own conclusions and can decide further course of action. However, a few points are important and require urgent management interventions. The tree species richness and diversity were found low in forest blocks, such as Lakkarkot, Lalwala, Sendhli, and Tira and the reason being presence of plantation patches of exotic species or monoculture. The elephants seldom use such areas as they have low availability of palatable shrubs and tree species and presence of weed further reduces utility of such areas by any other herbivores. It is therefore suggested that plantation patches of single species may gradually be replaced by the mixed plantation of native species those constitute elephant food tree species, except *Mallotus*, which is doing well otherwise. The forest blocks at the periphery of the Rajaji boundary may be taken up for gap filling plantations at places where canopy is reasonably open.

The invasion by the *Lantana camara* has been noticed and it has already established in several of the forest blocks. The situation is alarming in forest blocks such as Baniawala, Lalwala and Tira where the weeds especially *Lantana* has out competed other species at shrub level. In other forest blocks such as Chillawala, Gaaj, Ganjarban, Gholna, Mohund Rasulpur and Sukh the proportion of *Lantana* is almost equal to the other shrubs. It is therefore urgent that *Lantana* eradication should be taken up on priority.

The diversity of trees and shrub species both were low in Sal forest on plains as well as on hills and *Mallotus philippensis* is the dominant species at shrub level and as an under story tree. The stands of Sal forest in Rajaji are heading towards the climax. Since the regeneration of Sal is poor all over the Shivaliks so it is in Rajaji, therefore the question is what shape the Sal forest would take in future. One possibility is that the *Mallotus* would replace Sal. However, *Mallotus* is a co-dominant of Sal; it is likely that with decrease in Sal, *Mallotus* would also be reduced in equal proportions. In such a situation, the ecological space would then be taken over by fast growing, fire and grazing resistant plant species thus rendering the habitat further unsuitable for elephants as well as for other herbivores. In my opinion, the rule "prevention is better than cure" should apply. The habitat manipulation practices should be taken up in pure stands of Sal either to assist natural regeneration of Sal or plantation of other native species by opening forest canopy to a reasonable extent. The forest officers are well trained and competent in employing such techniques and have already demonstrated success by initiating such programmes elsewhere. The regeneration of few other species such as *Terminalia alata, Dalbergia sissoo* and *Anogeissus latifolia* is also poor as indicated by the population structures of these species, it is therefore recommended that in order to keep populations of such species healthy, efforts should be made to increase their regeneration level.

The stand level population structure of tree species in different forest blocks suggest that in some forest blocks the trend in tree population is of decreasing type mainly due to overall poor regeneration. Such forest blocks are Baniawala, Mohund, Gaaj, Chillawala, Gholna and Betban, which require management interventions.

Proportionately high extent of lopping has been noticed in Bam, Betban, Chillalwala and Gholna forest blocks. Since it is not practical to suggest that lopping should be banned completely, considering the socio-political scenario of Rajaji, it is therefore suggested that these forest blocks should be closed first and lopping should be allowed on rotational basis as has been a practice in the past. However, this would require a considerable political will rather than a simple decision at the level of Director National Park or other forest officials.

8.6.3 Elephant movements and ranging pattern vis-à-vis management implications

Elephant movement and ranging pattern in Rajaji are indicative that in order to ensure log-term survival of elephants in this region, some management interventions are required. The present study on movements and ranging pattern has very clearly showed that elephants establish their seasonal ranges based on considerations of food and water availability. These seasonal ranges may be established far apart from each other and hence elephant require much larger area than presently designated as National Park in order to utilize resources optimally in a sustainable manner. The elephants of Rajaji WLS during summer move out to either Motichur WLS or to Shivalik FD. The movements into Shivalik FD seems to be in response to the degradation and heavy human presence around the corridor between Rajaji-Motichur and Chilla units through which the groups have stopped moving over to Chilla. In such a situation, the elephants inhabiting Rajaji-Motichur unit have two options, to remain confined to Rajaji and Motichur WLS, which may not be sustainable considering present level of elephant population and the extent of the area (about 150 elephants, 550 km^2 of area). Further increase in population would certainly cause problems. The other option is to move to adjacent forest areas, which is the case as evident by movement of elephant groups into Shivalik FD. Therefore, in a perspective of long-term solution it is important that enhanced protection should be accorded to adjoining forest areas. At present, the forest in Shivalik FD seems to in degraded condition. It is therefore highly recommended that habitat improvement programme should be initiated on priority to make existing degraded habitat suitable for elephant use.

It has been realized long back that the corridor between Rajaji-Motichur and Chilla units is important at least in avoiding genetic isolation between the groups of elephant inhabiting the two units. The present study also proves the point as solitary males still move through this corridor. It is at important that conservation measures be taken to keep the corridor intact.

The larger part of elephant population of Rajaji-Motichur unit inhabit Rajaji WLS. Various censuses carried out by the Forest Department also confirm that the elephant density in Motichur was always much lower as compared to Rajaji. The results of present study on ranging pattern of elephants also showed occasional use of Motichur forests. The reason being presence of pure Sal forest on the gentler slopes of Motichur WLS, which has low tree species diversity and richness and do not offer much food to elephants. It has also been concluded during the present study that during summer ranging and movements of elephants are governed more by the availability of water than the quality of forage. Considering that Motichur WLS holds more water than Rajaji, it is expected that elephants would move and utilize Motichur area. However, it does not happen, which leads to conclusion that availability of forage is extremely low in Motichur. It is therefore recommended that habitat manipulation should be taken on small scale first to see the likely response of elephant population.

It is evident in Chilla that elephant groups are utilizing smaller range area, which is a case of compression of ranges in view of high densities. This can be further strengthened by the census figure, which estimates elephant numbers in Chilla to be approximately 300 in an area of 351 km^2. The seasonal range of two elephants had shown that elephants use areas out side the boundary of Chilla WLS specially into Chandi Forest Range. This calls for increasing the area of Chilla WLS to include Chandi Range. However, this seems a little difficult than declaring additional area under the "Elephant Reserve".

The future of Chilla elephants is linked with the protection of corridor between Chilla and Kalagarh FD as referred above in this chapter. Elephants are still using the KEC in order to seasonally move between Chilla and Kalagarh, which extends up to Corbett N.P. Special attention is required to reduce biotic pressures within the corridor and improve the forest condition by extensive plantations of native and elephant food tree species, especially bamboo.

8.6.4 Grouping pattern vis-à-vis management implications

The elephant group size seems to be a function of overall density of elephants in an area. If this is the governing factor than larger groups are expected in Chilla WLS as compared to Rajaji. However, a reverse pattern of this was observed and it was concluded that larger groups in Rajaji are in response to high degree of disturbance. Apparently, the degree of human interference is higher in Chilla than in Rajaji. However, a close examination reveals the situation to be otherwise. Gujjar settlements in Rajaji are more evenly spaced out than they are in Chilla and except Dholkhund area presence of Gujjar is everywhere in Rajaji which causes compression effect on the elephants and hence larger groups are formed in small undisturbed areas. Some corrective steps are necessary in allotment of areas to Gujjar so that they are neither concentrated at few places not dispersed evenly through out the area.

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